

South Dakota State University

## Open PRAIRIE: Open Public Research Access Institutional Repository and Information Exchange

---

Electronic Theses and Dissertations

---

2008

### Interannual Variation in Larval Yellow Perch Abundance in Eastern South Dakota Glacial Lakes and Relation to Sympatric Walleye Populations

Andrew C. Jansen

*South Dakota State University*

Follow this and additional works at: <https://openprairie.sdstate.edu/etd>

 Part of the [Natural Resources and Conservation Commons](#)

---

#### Recommended Citation

Jansen, Andrew C., "Interannual Variation in Larval Yellow Perch Abundance in Eastern South Dakota Glacial Lakes and Relation to Sympatric Walleye Populations" (2008). *Electronic Theses and Dissertations*. 483.

<https://openprairie.sdstate.edu/etd/483>

This Thesis - Open Access is brought to you for free and open access by Open PRAIRIE: Open Public Research Access Institutional Repository and Information Exchange. It has been accepted for inclusion in Electronic Theses and Dissertations by an authorized administrator of Open PRAIRIE: Open Public Research Access Institutional Repository and Information Exchange. For more information, please contact [michael.biondo@sdstate.edu](mailto:michael.biondo@sdstate.edu).

**Interannual Variation in Larval Yellow Perch Abundance in Eastern South Dakota  
Glacial Lakes and Relation to Sympatric Walleye Populations**

BY

Andrew C. Jansen

A thesis submitted in partial fulfillment of the requirements for the

Master of Science

Major in Wildlife and Fisheries Sciences (Fisheries Option)

South Dakota State University

2008

**Interannual Variation in Larval Yellow Perch Abundance in Eastern South Dakota  
Glacial Lakes and Relation to Sympatric Walleye Populations**

This thesis is approved as a creditable and independent investigation by a candidate for the Master of Science degree and is acceptable for meeting the thesis requirements for this degree. Acceptance of this thesis does not imply that the conclusions reached by the candidate are necessarily the conclusions of the major department.

---

Dr. David W. Willis  
Major Advisor

Date

---

Dr. David W. Willis  
Head, Department of Wildlife and Fisheries  
Sciences

Date

## ACKNOWLEDGMENTS

First and foremost, I would like to thank my advisor Dr. Dave Willis for his continual guidance and dedication through this entire process. The patience of Dr. Willis and Dr. Brian Graeb has allowed me to “embrace the uncertainty” and accept that “it is, what it is”; valuable life lessons to which I am forever in their debt. I also extend my gratitude to my committee members Dr. Brian Blackwell and Dr. Cynthia Elverson. I would like to thank my parents and family for their unrelenting support and for introducing me to the outdoors at an early age. To my brother Jared, your interest in fish and fishing is my inspiration for continuing to strive to protect fisheries resources for the many generations to come. I gratefully acknowledge the previous yellow perch researchers in South Dakota for providing the groundwork analyses utilized for this project. I would like to thank all of the graduate students for making my stay here very enjoyable and memorable. A special thanks to Tom and Heather Bacula, Kris Edwards, Bryan Spindler, and Travis Runia. Thank you to the many graduate and undergraduate students for their assistance in the field and lab, especially Jonah Dagel, Nikki Lorenz, Nathan Pool, Austin DeWitte, Nick Peterson, Tanner Pruess, and Scott Heidebrink. I would also like to thank other members of the Willis lab including: Jeff Jolley, Justin VanDeHey, and Melissa Wuellner.

Partial funding for this research was provided by the Federal Aid in Sport Fish Restoration program, Project F-15-R, Study 1506, administered through South Dakota Department of Game, Fish and Parks.

## **ABSTRACT**

### **Interannual Variation in Larval Yellow Perch Abundance in Eastern South Dakota Glacial Lakes and Relation to Sympatric Walleye Populations**

**Andrew C. Jansen**

**November 2008**

Yellow perch *Perca flavescens* are a popular sportfish in eastern South Dakota glacial lakes. In addition to their recreational importance, yellow perch serve as a prey species for predators. Thus, understanding the factors that affect yellow perch population dynamics is a top priority among fishery managers in South Dakota. The objectives of this study were to 1) estimate the magnitude and duration for a decrease in water temperature that would induce mortality of yellow perch eggs, 2) investigate the relation between climatological variables and larval perch abundance in six eastern South Dakota glacial lakes, and 3) relate long-term larval perch abundance to walleye growth and condition in six eastern South Dakota glacial lakes.

For my first objective, yellow perch egg skeins were collected from nearby lakes in spring 2007 and 2008 and transferred to a laboratory tank system. Egg skeins were split into multiple sections to minimize any individual, maternal effects and randomly allocated to treatment or control tanks. The first experiment decreased water temperature by 6°C in 24 h; however, no significant difference in mean hatch success was observed between treatment and control tanks (control 55%, SE=6.0; treatment 48%, SE=5.8). In

the next experiment, we increased the magnitude (8°C) and decreased the duration (45 min) to determine the lower end of the temperature threshold. Again no significant difference in mean hatch success was observed between treatment and control tanks (control 38%, SE=5.0; treatment 37%, SE=5.6). I conclude that a decrease in water temperature associated with a cold-front likely has little effect on yellow perch egg survival in South Dakota waters. I suggest that further research is needed on the effect of simulated cold-fronts on larval yellow perch development and survival during the switch to exogenous feeding.

To address my second objective, I utilized three climatological predictor variables (mean March wind speed, total April precipitation, and mean May temperature) that were found to have relations with larval yellow perch abundance in a previous study. Larval yellow perch were collected from six lakes in eastern South Dakota from 1995 to 1997 and 2000 to 2008 using a 0.75-m, 1,000- $\mu$ m mesh (bar measure) ichthyoplankton surface trawl fitted with a flowmeter to determine larval density. Correlation analysis was used to assess the relation between larval yellow perch abundance and the predictor variables within and among lakes. I also used Akaike's Information Criterion to assess variability in larval yellow perch abundance in relation to climatological predictor variables. In general, larval yellow perch abundance was negatively correlated with mean March wind speed, and positively correlated with total April precipitation and mean May temperature. The most influential variable in predicting larval yellow perch abundance seemed to vary by lake. Therefore, I suggest that future research be restricted to lake-specific analyses. Additionally, I believe the time at which larval yellow perch switch to exogenous feeding

may be a critical life stage in the early life history of perch and further research should focus on the relation of climate variables within this time period to larval perch abundance.

For my final objective, I utilized the same larval yellow perch abundance data from objective 2 to examine the relation of yellow perch as prey for walleye. Age-0 walleye growth and adult walleye condition data were compiled from South Dakota Department of Game, Fish and Parks annual lake surveys. I used mean total length of age-0 walleye captured during fall night electrofishing as an index of age-0 walleye growth and mean relative weight by size category as an index of adult walleye condition. Correlation analysis was used to assess relations between age-0 walleye growth and age-0 walleye catch per unit effort (i.e., density-dependent growth), larval yellow perch density, and cumulative warming degree days. Weak relations between these predictor variables and age-0 walleye growth were observed. Similarly, weak correlations were observed between larval yellow perch density and adult walleye condition. Akaike's Information Criterion analysis was used to assess variability in age-0 walleye growth with the predictor variables. Cumulative warming degree days was selected as the best candidate model in predicting age-0 walleye growth. However, other models were competing, indicating limited performance of the candidate models in explaining age-0 walleye growth. I believe that when alternative prey items are sufficiently abundant, walleyes can maintain growth and condition in the absence of yellow perch. I recommend that future research be restricted to lake-specific comparisons due to variability among populations.

## TABLE OF CONTENTS

Interannual Variation in Larval Yellow Perch Abundance in Eastern South Dakota Glacial Lakes and Relation to Sympatric Walleye Populations .....	i
ACKNOWLEDGMENTS .....	iii
ABSTRACT .....	iv
LIST OF TABLES .....	ix
LIST OF FIGURES .....	x
CHAPTER 1. INTRODUCTION .....	1
CHAPTER 2. EFFECT OF A SIMULATED COLD-FRONT ON HATCHING SUCCESS OF YELLOW PERCH EGGS .....	7
Introduction.....	7
Methods.....	8
Results.....	10
Discussion.....	11
CHAPTER 3. INTERANNUAL VARIATION IN LARVAL YELLOW PERCH ABUNDANCE IN EASTERN SOUTH DAKOTA GLACIAL LAKES AND RELATION TO CLIMATOLOGICAL VARIABLES .....	15
Introduction.....	15
Methods.....	16
Results.....	18
Discussion.....	19



CHAPTER 4. RELATION BETWEEN AGE-0 YELLOW PERCH ABUNDANCE AND WALLEYE GROWTH AND CONDITION IN EASTERN SOUTH DAKOTA GLACIAL LAKES .....	30
Introduction.....	30
Methods.....	31
Results.....	33
Discussion .....	34
CHAPTER 5. SUMMARY AND RESEARCH NEEDS .....	52
REFERENCES .....	55

## LIST OF TABLES

Table 1-1. Date and associated peak larval yellow perch abundance (mean number/100 m <sup>3</sup> ) for six glacial lakes in eastern South Dakota obtained from surface trawling from 1995 to 1997 and 2000 to 2008. SE is standard error of the mean peak larval yellow perch density, n is the number of the trawl tows performed on the peak density date, and mesh is the size of the bar mesh ( $\mu$ m) on the larval trawl used to collect the larval perch .....	4
Table 1-2. Surface area (ha), maximum depth (m), and trophic status of six glacial lakes in eastern South Dakota. Trophic status was based on Carlson's (1977) trophic state index. All lake information was extracted from Stukel (2003) except for Lake Enemy Swim which was from Stueven and Stewart (1996) .....	6
Table 2-1. Summary statistics from simulated cold-front experiments on hatch success of yellow perch eggs. The simulated cold-front in 2007 decreased water temperature from 12 to 6°C in 24 h while the 2008 experiment decreased water temperature from 11 to 3°C in 45 min. A parametric t-test (TTEST procedure; SAS Institute 2004) was used to assess differences in mean hatch between control and cold-front tanks .....	14
Table 3-1. Akaike's Information Criterion (AIC) values relating larval yellow perch abundance with important predictor variables for Lakes Brant, Enemy Swim, Madison, Pickerel, Sinai, and Waubay in eastern South Dakota. The main effects (in addition to the intercept and error term) are designated as K, n is the number of observations, $\Delta_i$ is the difference in AICc values. Models were ranked by lowest $\Delta_i$ values and highest Akaike weight ( $w_i$ ) (i.e. indicates most support). Wind = mean March wind speed (km/h); Precip = total April precipitation (cm); Temp = mean May temperature (°C) (see text for complete description of variables).....	23
Table 4-1. Akaike's Information Criterion (AIC) values relating first-year walleye growth with important predictor variables for Lakes Brant, Enemy Swim, Madison, Pickerel, Sinai, and Waubay in eastern South Dakota. The main effects (in addition to the intercept and error term) are designated as K, n is the number of observations, $\Delta_i$ is the difference in AICc values. Models were ranked by lowest $\Delta_i$ values and highest Akaike weight ( $w_i$ ) (i.e. indicates most support). DegDays = cumulative warming degree days (i.e. number of days > 10°C from April-September); CPUE = mean catch per unit effort of age-0 walleyes captured during fall, night electrofishing surveys; Larv = peak larval yellow perch abundance (mean number/100 m <sup>3</sup> ) (see text for complete description of variables).....	39

## LIST OF FIGURES

Figure 3-1. Relations between mean March wind speed (km/h) and larval yellow perch (YEP) abundance (number/100 m <sup>3</sup> ) determined during larval trawling for six eastern South Dakota glacial lakes sampled from 1995 to 1997 and 2000 to 2008 .....	24
Figure 3-2. Relation between mean March wind speed (km/h) and larval yellow perch (YEP) abundance (number/100 m <sup>3</sup> ) determined during larval fish trawling for Lakes Brant, Enemy Swim, Madison, Pickerel, Sinai, and Waubay in eastern South Dakota sampled from 1995 to 1997 and 2000 to 2008.....	25
Figure 3-3. Relation between total April precipitation (cm) and larval yellow perch (YEP) abundance (number/100 m <sup>3</sup> ) determined during larval fish trawling for six eastern South Dakota glacial lakes sampled from 1995 to 1997 and 2000 to 2008.....	26
Figure 3-4. Relation between total April precipitation (cm) and larval yellow perch (YEP) abundance (number/100 m <sup>3</sup> ) determined during larval fish trawling for Lakes Brant, Enemy Swim, Madison, Pickerel, Sinai, and Waubay in eastern South Dakota sampled from 1995 to 1997 and 2000 to 2008.....	27
Figure 3-5. Relation between mean May temperature (°C) and larval yellow perch (YEP) abundance (number/100 m <sup>3</sup> ) determined during larval fish trawling for six eastern South Dakota glacial lakes sampled from 1995 to 1997 and 2000 to 2008.....	28
Figure 3-6. Relation between mean May temperature (°C) and larval yellow perch (YEP) abundance (number/100 m <sup>3</sup> ) determined during larval fish trawling for Lakes Brant, Enemy Swim, Madison, Pickerel, Sinai, and Waubay in eastern South Dakota sampled from 1995 to 1997 and 2000 to 2008.....	29
Figure 4-1. Relations between age-0 walleye (WAE) mean catch per unit effort (CPUE) and mean total length (TL) of age-0 walleye captured during fall night electrofishing for six study lakes in eastern South Dakota, 2000-2006 .....	40
Figure 4-2. Relations between cumulative warming degree days (number of days > 10°C from April to September) and mean total length (TL) of age-0 walleye (WAE) captured during fall night electrofishing for six study lakes in eastern South Dakota, 2000-2006 .....	41

Figure 4-3. Relations between larval yellow perch (YEP) abundance and mean total length (TL) of age-0 walleye (WAE) captured during fall night electrofishing for six study lakes in eastern South Dakota, 2000-2006.....	42
Figure 4-4. Relation between age-0 walleye (WAE) mean catch per unit effort (CPUE) and mean total length (TL) of age-0 walleye captured during fall night electrofishing for Lakes Brant, Enemy Swim, Madison, Pickerel, Sinai, and Waubay in eastern South Dakota, 2000-2006.....	43
Figure 4-5. Relation between cumulative warming degree days (number of days > 10°C from April to September) and mean total length (TL) of age-0 walleye (WAE) captured during fall night electrofishing from Lakes Brant, Enemy Swim, Madison, Pickerel, Sinai, and Waubay, 2000-2006 .....	44
Figure 4-6. Relation between larval yellow perch (YEP) abundance and mean total length (TL) of age-0 walleye (WAE) captured during fall night electrofishing for Lakes Brant, Enemy Swim, Madison, Pickerel, Sinai, and Waubay, 2000-2006.....	45
Figure 4-7. Relations between larval yellow perch (YEP) abundance and adult walleye (WAE) mean relative weight (Wr) by length category [Gabelhouse 1984; sub-stock (SS)=15-25 cm; stock (S)=25-76 cm; stock-quality (S-Q)=25-37 cm; quality-preferred (Q-P)=38-50 cm; preferred-memorable (P-M)=51-62 cm; memorable-trophy (M-T)=63-76 cm] for Lake Brant in eastern South Dakota, 2001-2007.....	46
Figure 4-8. Relations between larval yellow perch (YEP) abundance and adult walleye (WAE) mean relative weight (Wr) by length category [Gabelhouse 1984; sub-stock (SS)=15-25 cm; stock (S)=25-76 cm; stock-quality (S-Q)=25-37 cm; quality-preferred (Q-P)=38-50 cm; preferred-memorable (P-M)=51-62 cm; memorable-trophy (M-T)=63-76 cm] for Lake Enemy Swim in eastern South Dakota sampled in 1997 and from 2000 to 2006.....	47
Figure 4-9. Relations between larval yellow perch (YEP) abundance and adult walleye (WAE) mean relative weight (Wr) by length category [Gabelhouse 1984; sub-stock (SS)=15-25 cm; stock (S)=25-76 cm; stock-quality (S-Q)=25-37 cm; quality-preferred (Q-P)=38-50 cm; preferred-memorable (P-M)=51-62 cm; memorable-trophy (M-T)=63-76 cm] for Lake Madison in eastern South Dakota, 2000-2007.....	48

- Figure 4-10. Relations between larval yellow perch (YEP) abundance and adult walleye (WAE) mean relative weight (Wr) by length category [Gabelhouse 1984; sub-stock (SS)=15-25 cm; stock (S)=25-76 cm; stock-quality (S-Q)=25-37 cm; quality-preferred (Q-P)=38-50 cm; preferred-memorable (P-M)=51-62 cm; memorable-trophy (M-T)=63-76 cm] for Lake Pickerel in eastern South Dakota sampled from 1995 to 1997 and from 2000 to 2007 .....49
- Figure 4-11. Relations between larval yellow perch (YEP) abundance and adult walleye (WAE) mean relative weight (Wr) by length category [Gabelhouse 1984; sub-stock (SS)=15-25 cm; stock (S)=25-76 cm; stock-quality (S-Q)=25-37 cm; quality-preferred (Q-P)=38-50 cm; preferred-memorable (P-M)=51-62 cm; memorable-trophy (M-T)=63-76 cm] for Lake Sinai in eastern South Dakota, 2000-2007 .....50
- Figure 4-12. Relations between larval yellow perch (YEP) abundance and adult walleye (WAE) mean relative weight (Wr) by length category [Gabelhouse 1984; sub-stock (SS)=15-25 cm; stock (S)=25-76 cm; stock-quality (S-Q)=25-37 cm; quality-preferred (Q-P)=38-50 cm; preferred-memorable (P-M)=51-62 cm; memorable-trophy length (M-T)=63-76 cm] for Lake Waubay in eastern South Dakota, 2000-2007 .....51

## CHAPTER 1. INTRODUCTION

Yellow perch *Perca flavescens* are an important component of many freshwater ecosystems. Yellow perch are a common diet item of many predator species. In particular, the walleye *Sander vitreus*, a popular North American sportfish, commonly utilize juvenile yellow perch as prey (Forney 1974, 1976; Madenjian 1991; Marwitz and Hubert 1997) including within South Dakota waters (Blackwell et al. 1999). In addition to their ecological importance as a prey species, yellow perch are also a popular sportfish to many anglers. In South Dakota, yellow perch are the third most sought-after sportfish by South Dakota anglers (Stone 1996). Thus, knowledge of the factors that affect yellow perch reproduction and subsequent recruitment is important to the management of sport fisheries in South Dakota.

Yellow perch recruitment is erratic in many South Dakota waters. Consequently, extensive research has been conducted on the early life history of yellow perch in eastern South Dakota glacial lakes. Since 1995, surface trawling for larval yellow perch has been used to index perch reproduction (Table 1-1). This information has been used to investigate a variety of research questions. Anderson et al. (1998) found that larval yellow perch abundance was positively correlated with fall juvenile abundance. Fisher (1996) investigated yellow perch spawning characteristics, embryo development, and life history of larval and juvenile perch. Isermann (2003) reported that single cohorts of larval yellow perch are produced each year over a relatively short time span and are subsequently susceptible to harsh environmental conditions. Ward et al. (2004)

investigated the effect of spring weather patterns on larval yellow perch abundance and found that larval perch abundance tended to be higher during years with less wind, more precipitation, and warmer air temperatures during spring. Although substantial research has been conducted, our understanding of the abiotic factors that may affect the early life history of yellow perch and their subsequent recruitment in South Dakota glacial lakes is limited.

The objectives of this study were to 1) estimate the magnitude and duration for a decrease in water temperature that would induce mortality of yellow perch eggs; 2) relate long-term trends in larval yellow perch abundance and climatological variables such as temperature, wind and precipitation and; 3) assess the potential relations between larval yellow perch abundance and walleye growth and condition in six eastern South Dakota glacial lakes.

### **Study Sites**

This study was conducted on six glacial lakes located in eastern South Dakota. Lakes Enemy Swim, Pickerel, and Waubay are located within 5 km of one another in Day County in northeastern South Dakota. Lake Sinai is located in western Brookings County, approximately 147 km south of the three lakes in Day County. Lakes Madison and Brant are located approximately 3 km from one another in south-central Lake County, approximately 31 km south of Lake Sinai.

The study lakes range widely in size (~300-6,000 ha), but in general are relatively shallow, productive aquatic systems (Table 1-2). Habitat composition and dynamics of the adult yellow perch population vary by lake. Extensive submergent vegetation

inhabits shallow areas of Lakes Enemy Swim and Pickerel. Yellow perch populations in these two lakes generally exhibit more consistent recruitment patterns, slow growth, and low size structure. Lakes Brant, Madison, Sinai, and Waubay have scattered submergent vegetation, while Lakes Sinai and Waubay also have flooded trees. Yellow perch populations in these four lakes generally exhibit inconsistent recruitment patterns, fast growth, and relatively high size structure.

The fish communities within each lake are dominated by yellow perch and walleye. However, other species present within the study lakes include: bigmouth buffalo *Ictiobus cyprinellus*, black bullhead *Ameiurus melas*, largemouth bass *Micropterus salmoides*, smallmouth bass *Micropterus dolomieu*, black crappie *Poxomis nigromaculatus*, channel catfish *Ictalurus punctatus*, common carp *Cyprinus carpio*, fathead minnow *Pimephales promelas*, johnny darter *Etheostoma nigrum*, lake herring *Coregonus artedii*, logperch *Percina caprodes*, northern pike *Esox lucius*, rock bass *Ambloplites rupestris*, spottail shiner *Notropis hudsonius*, sunfishes *Lepomis* spp., white bass *Morone chrysops*, and white sucker *Catostomus commersonii*.



Table 1-1. Date and associated peak larval yellow perch abundance (mean number/100 m<sup>3</sup>) for six glacial lakes in eastern South Dakota obtained from surface trawling from 1995 to 1997 and 2000 to 2008. SE is standard error of the mean peak larval yellow perch density, n is the number of the trawl tows performed on the peak density date, and mesh is the size of the bar mesh ( $\mu$ m) on the larval trawl used to collect the larval perch.

Lake	Year	Date of peak larval density	Peak (mean number/100 m <sup>3</sup> )	SE	N	Mesh ( $\mu$ m)
Brant	2001	24-May	6.29	4.22	6	1,000
	2002	4-Jun	0.61	0.41	6	1,000
	2003	4-Jun	1.7	0.8	6	1,000
	2004	no larvae	0	0	6	1,000
	2005	18-May	0.20	0.20	6	1,000
	2006	no larvae	0.00	0.00	6	1,000
	2007	17-May	3.85	1.19	6	1,000
	2008	10-Jun	0*	0.09	6	1,000
Enemy Swim	1997	27-May	178	33	6	500
	2000	22-May	342	83	12	1,000
	2001	27-May	220	49	12	1,000
	2002	5-Jun	35	8.5	12	1,000
	2003	27-May	120	39	12	1,000
	2004	28-May	28.9	1.8	6	1,000
	2005	30-May	82.90	39.29	6	1,000
	2006	26-May	10.55	5.12	6	1,000
	2007	22-May	8.35	2.84	6	1,000
	2008	6-Jun	2.2	1.19	6	1,000
Madison	2000	19-May	9.3	3.4	16	1,000
	2001	24-May	7.7	2.4	16	1,000
	2002	11-Jun	0.08	0.08	16	1,000
	2003	4-Jun	0.32	0.14	16	1,000
	2004	26-May	0.9	0.3	6	1,000
	2005	19-May	0.27	0.18	6	1,000
	2006	15-May	0.8	0.54	6	1,000
	2007	17-May	0.73	0.73	6	1,000
	2008	no larvae	0	0	6	1,000

\*one larval yellow perch captured on two separate sample dates

Table 1-1. (continued).

Lake	Year	Date of peak larval density	Peak (mean number/100 m <sup>3</sup> )	SE	N	Mesh ( $\mu$ m)
Pickereel	1995	1-Jun	20	5	6	500
	1996	5-Jun	190	55	6	500
	1997	27-May	84	25	6	500
	2000	22-May	69	12	10	1,000
	2001	27-May	111	36	10	1,000
	2002	5-Jun	109	42	10	1,000
	2003	3-Jun	21	9	10	1,000
	2004	18-May	172.8	82.8	6	1,000
	2005	30-May	171.77	93.52	6	1,000
	2006	26-May	31.02	10.01	6	1,000
	2007	23-May	58.68	22.18	6	1,000
	2008	29-May	64.99	38.37	6	1,000
Sinai	1997	4-Jun	2.7	0.9	6	500
	2000	12-May	4.2	2.4	10	1,000
	2001	24-May	3097	2915	10	1,000
	2002	10-Jun	1.2	0.7	10	1,000
	2003	21-May	0.06	0.06	10	1,000
	2004	28-May	0.7	0.5	6	1,000
	2005	23-May	1.70	1.00	6	1,000
	2006	15-May	0.32	0.22	6	1,000
	2007	31-May	0.11	0.11	6	1,000
	2008	10-Jun	0.88	0.42	6	1,000
Waubay	2000	25-May	5	2	20	1,000
	2001	6-Jun	224	48	20	1,000
	2002	no larvae	0	0	20	1,000
	2003	3-Jun	1.9	0.7	20	1,000
	2004	27-May	0.2	0.2	6	1,000
	2005	23-May	0.56	0.46	6	1,000
	2006	no larvae	0	0	6	1,000
	2007	23-May	3.2	1.78	6	1,000
	2008	16-Jun	0.43	0.22	6	1,000

Table 1-2. Surface area (ha), maximum depth (m), and trophic status of six glacial lakes in eastern South Dakota. Trophic status was based on Carlson's (1977) trophic state index. All lake information was extracted from Stukel (2003) except for Lake Enemy Swim which was from Stueven and Stewart (1996).

Lake	Surface area (ha)	Maximum depth (m)	Trophic status
Pickerel	397	12.5	Mesotrophic
Brant	420	4.3	Mesotrophic
Sinai	696	10.1	Eutrophic
Enemy Swim	868	7.9	Mesotrophic
Madison	1,069	4.9	Eutrophic
Waubay	6,293	10.7	Eutrophic

## **CHAPTER 2. EFFECT OF A SIMULATED COLD-FRONT ON HATCHING SUCCESS OF YELLOW PERCH EGGS**

### **Introduction**

Yellow perch recruitment is erratic in many South Dakota waters and extensive research has been conducted on perch early life history. Surface trawling for larval yellow perch has been used to index reproduction in eastern South Dakota glacial lakes since 1995, and larval perch abundance has been highly variable among lakes and among years (Ward et al. 2004). Isermann and Willis (2008) suggested that factors prior to, during, or immediately following hatching may play a critical role in establishment of yellow perch year-class strength. Many factors can affect fish egg survival, including sedimentation (Reiser and White 1988; Lapointe et al. 2004; Levasseur et al. 2006), dissolved oxygen (Geist et al. 2006), predation (Newsome and Tompkins 1985; Diamond and Wakefield 1986), temperature (Hokansen and Kleiner 1974; Guma'a 1978; Huff et al. 2004), ultra-violet radiation (Huff et al. 2004), and maternal characteristics (Heyer et al. 2001; Johnston et al. 2007).

Temperature, in particular, has been hypothesized to play a primary role in determining yellow perch egg survival. In general, a higher abundance of yellow perch swim-up larvae are produced when water temperatures gradually increase (Hokanson and Kleiner 1974). The gradual increase in water temperature also creates a shorter hatching period and fewer abnormalities in larvae (Hokanson and Kleiner 1974). Guma'a (1978) contended that the optimal water temperature range for Eurasian perch *Perca fluviatilis*

eggs occurs between 8 and 12°C. However, little information exists on the effects of declining temperatures on yellow perch egg survival. Longhenry (2006) attributed the lack of larval yellow perch abundance in semi-permanent wetlands in South Dakota to a cold-front that decreased the water temperature from 12°C to 8°C in 24 h. Therefore, I chose to investigate a rapid decrease in water temperature as a potential mechanism that would affect yellow perch eggs. The objective of this study was to simulate a cold-front in a laboratory setting to estimate the magnitude and duration for a decrease in water temperature that would induce mortality of yellow perch eggs.

### **Methods**

Yellow perch egg skeins were collected from a private lake near Brookings, South Dakota in 2007 and from East Oakwood Lake, South Dakota in 2008. Eggs were collected on 24 April of both years. Egg skeins were transported to a fish holding facility at South Dakota State University and were held at a constant temperature (12°C) for 24 h to ensure that no substantial mortality was caused by transport. Two flow-through aquaculture tank systems were used for these experiments. One tank system was designated the control temperature and the other was designated the treatment (i.e., cold-front) temperature. Each tank system had a head tank powered with a 246-W chiller (FRIGID Units, Inc.; Toledo, Ohio) and gravity-fed dechlorinated water that was distributed to eight, 38-L aquaria. Each aquarium within the system was split into two compartments using 500- $\mu$ m mesh screen and two hatching baskets were then placed into each compartment. Egg skeins were cut into 5-cm sections, weighed, and randomly assigned an aquarium and placement location within the aquarium. One egg section from

each skein was preserved in formalin for later determination of average number of eggs per section.

In 2007, the cold-front treatment decreased water temperature from 12 to 6°C in 24 h. The temperature remained at 6°C for 48 h, and then was slowly increased back to the control temperature over 48 h. Egg mortality was qualitatively assessed daily to determine immediate effects of the treatment. Once hatching was initiated, larvae were removed from the tank systems daily and preserved in 90% ethanol for later enumeration and determination of hatch success.

In 2008, the cold-front treatment decreased water temperature from 11 to 3°C in 45 min. The same protocol as the 2007 experiment was used for this experiment; however, a 746-W chiller (FRIGID Units, Inc.; Toledo, Ohio) was used for the treatment tank system to decrease the temperature more rapidly. Additionally, dechlorinated ice was added to the treatment head tank to augment the decrease in temperature. Ice was also added to each aquarium in the treatment tank system to decrease the amount of time required to reach the desired temperature within the aquaria. Again, once hatching was initiated, larvae were removed from the tank systems daily and preserved for later enumeration and determination of hatch success.

Total number of larvae per aquarium compartment was enumerated for each experiment. A mean percent hatch for each aquarium section was calculated by dividing the number of larvae produced by the average number of eggs in each egg section multiplied by 100. I tested the normality and homogeneity of variance of the data (UNIVARIATE procedure; Statistical Analysis Software [SAS] Institute 2004) and met

the assumptions for parametric analysis. Therefore, I used a t-test (TTEST procedure; SAS Institute 2004) to assess differences in mean percent hatch (as a decimal fraction) between control and treatment tanks. Total time to complete hatching (days) was calculated as the day hatching began through the end of hatching.

### **Results**

Substantial mortality due to transport was not observed for the 2007 experiment. However, a remnant of egg skeins was accidentally left in one tank in the control system, so that tank was subsequently removed from analysis. During the 2008 experiment, substantial mortality due to transport was observed for one tank in the treatment system, which was subsequently removed from analysis. Daily qualitative (i.e., visual) assessments of egg mortality suggested that the treatment temperature changes had no immediate effects on egg survival for either experiment.

Mean percent hatch was not significantly different between treatment and control tank systems from the 2007 experiment in which water temperature decreased from 12 to 6°C over 24 h ( $t_s = -1.09$ ,  $df = 13$ ,  $P = 0.29$ ; Table 2-1). Total time to complete hatching was 4 d for control tanks and 8 d for treatment tanks. Control tanks began hatching 1 d prior to hatching initiated in the treatment tanks.

In the 2008 experiment in which water temperature decreased from 11 to 3°C in 45 min, mean percent hatch was not significantly different between treatment and control tank systems ( $t_s = -0.18$ ,  $df = 13$ ,  $P = 0.86$ ; Table 2-1). Total time to complete hatching was 7 d for control tanks and 7 d for treatment tanks. Control tanks began hatching 2 d prior to hatching initiated in the treatment tanks.

## Discussion

These experiments indicated that a decrease in water temperature associated with a cold-front in the spring likely has little effect on the hatch success of yellow perch eggs in South Dakota waters. Surprisingly, the 2008 experiment, which represented an “extreme” weather event, had little effect on yellow perch egg hatch success. Therefore, I conclude that the egg stage of the yellow perch early life history life cycle is more hardy than previously believed. However, changes in environmental conditions post-hatch may affect yellow perch early life history and subsequent recruitment of a year class.

Although this study indicated that substantial changes in water temperature had little effect on yellow perch egg hatching success, other potential factors that were not evaluated may play a vital role in determining perch year-class strength. Maternal characteristics such as ovum size, lipid content, and fatty acid concentration have been related to embryo survival in walleyes (Johnston et al. 2007). Although these maternal characteristics were not evaluated in my study, sections of egg skeins from multiple females were randomly assigned to treatments to reduce maternal effects. Additionally, within my 2-year study no differences in embryo survival were noted; therefore, I suspect that maternal characteristics may not be limiting hatch success of yellow perch eggs in South Dakota waters.

Egg predation may also affect yellow perch egg survival and was not evaluated. Predation of yellow perch eggs by aquatic invertebrates (Diamond and Wakefield 1986) and fish (Newsome and Tompkins 1985) have been documented, although predation was



minimal in both cases. Wells (1977) suggested that the gelatinous material surrounding the yellow perch eggs buffers the eggs from predation.

Yellow perch egg survival may potentially be affected by the sedimentation caused by strong winds. Previous research indicated that in shallow, wind-swept lakes yellow perch eggs may become dislodged and egg mortality increases (Clady and Hutchinson 1975). Eggs may be harmed by physical damage due to washing ashore onto the substrate or eggs may be transported to undesirable locations within a lake (e.g.; turbid or cold temperature; Aalto and Newsome 1993). However, Fisher et al. (1996) noted that yellow perch in Pickerel Lake, South Dakota deposited their eggs in areas unprotected from the wind. No egg masses were found washed ashore nor was there any damage or deformities in egg masses collected (Fisher 1996). The effect of wind on post-hatching survival of larvae warrants further investigation.

Future research on yellow perch recruitment should focus on identifying the critical life stage of perch in eastern South Dakota glacial lakes. Yellow perch larvae at the yolk-sac stage or when switching to exogenous feeding may be more vulnerable to water temperature changes than eggs. Previous research suggested that the time at which larval fish switch to exogenous feeding is a critical period (Sifa and Mathias 1987), and yellow perch make the switch from endogenous to exogenous feeding at approximately 1 week of age (Post and McQueen 1988). Graeb et al. (2004) indicated that the preferred zooplankton taxa for larval yellow perch were copepods (nauplii and adults); thus, the availability of these taxa may affect larval perch survival.

My study also indicated that although hatch success between treatment and control tanks was not significantly different, timing of hatch was affected by the change in water temperature. This delay of hatch may or may not coincide with the size and abundance of available zooplankton for larval yellow perch foraging (i.e., match-mismatch hypothesis, Cushing 1990). I suggest that a more comprehensive study on the switch to the exogenous-feeding life stage and available prey is needed. This information will be vital to better understand the role of environmental changes on the early life history of yellow perch and subsequent establishment of a year class.

Table 2-1. Summary statistics from simulated cold-front experiments on hatch success of yellow perch eggs. The simulated cold-front in 2007 decreased water temperature from 12 to 6°C in 24 h while the 2008 experiment decreased water temperature from 11 to 3°C in 45 min. A parametric t-test (TTEST procedure; SAS Institute 2004) was used to assess differences in mean hatch between control and cold-front tanks.

Year	Treatment	N	Mean hatch (decimal fraction)	SE	Range	$t_s$	$P$
2007	Control	7	0.55	0.05	(0.37-0.72)	-1.09	0.2941
	Cold-front	8	0.48	0.04	(0.30-0.72)		
2008	Control	8	0.38	0.03	(0.26-0.49)	-0.18	0.8575
	Cold-front	7	0.37	0.08	(0.10-0.69)		

### **CHAPTER 3. RELATION OF CLIMATOLOGICAL VARIABLES TO INTERANNUAL VARIATION IN LARVAL YELLOW PERCH ABUNDANCE IN EASTERN SOUTH DAKOTA GLACIAL LAKES**

#### **Introduction**

Yellow perch are both a popular sportfish and an important prey fish in eastern South Dakota waters. Stone (1996) found that yellow perch were the third most popular sportfish in South Dakota waters. Additionally, yellow perch are commonly used by walleye as prey (Blackwell et al. 1999), which is the most popular sportfish in South Dakota waters (Stone 1996). Thus, knowledge of the factors that affect yellow perch reproduction and subsequent recruitment is important to the management of sport fisheries in South Dakota.

Many abiotic factors can affect the early life history of yellow perch. Survival from the egg to larval life stage of yellow perch was positively related to spring air temperature in Oneida Lake, New York (Clady 1976). Relative abundance of age-0 yellow perch was also correlated with spring air temperatures in Kabetogama and Sand Point lakes, Minnesota (Kallemeyn 1987). Similarly, Eshrenroder (1977) suggested that spring water temperature influenced yellow perch recruitment in Saginaw Bay. Spring precipitation may also affect yellow perch survival as water level has been related to perch year-class strength (Henderson 1985; Kallemeyn 1987). Wind can negatively affect the early survival of yellow perch (Clady 1976). Aalto and Newsome (1993) suggested that wind may affect yellow perch embryonic development or cause physical

damage to larvae. In South Dakota, larval (Ward et al. 2004) and juvenile (Pope et al. 1996) yellow perch abundance tended to be higher during years with less wind, more precipitation, and warmer air temperatures during spring.

Although Ward et al. (2004) provided preliminary information on climatological relations with interannual variation in larval yellow perch abundance in South Dakota waters, a more comprehensive study is needed to confirm potential effects. A more robust study will allow fishery managers to better predict abundance of larval yellow perch and subsequently be able to predict fluctuations in perch fisheries. Therefore, the objective of my study was to relate long-term trends in larval yellow perch abundance to climatological variables in eastern South Dakota glacial lakes.

### **Methods**

Larval fish sampling was conducted from early May through mid-June at 7- to 10-d intervals using a 0.75-m, 500-1,000- $\mu$ m mesh (bar measure) ichthyoplankton surface trawl fitted with a flowmeter (General Oceanics Model #2030R; Miami, FL) in the mouth of the trawl. A gear comparison study by Isermann et al. (2002) found no significant differences in larval yellow perch density estimates between the 500- and 1000- $\mu$ m mesh size trawls. The trawl was towed in a circular pattern within the upper 1 m of the water column for 3-5 min at an average speed of 1 m/s. Tow duration was adjusted according to plankton abundance as larval fish capture efficiency decreased as plankton (phytoplankton and zooplankton) abundance increased. Number of sites sampled per collection trip ranged from three to 10 sites from 1995 to 2003 as study objectives varied across years (Fisher 1996; Anderson et al. 1997; Isermann 2003; Ward et al. 2004). From

2004 to 2008, three sites were sampled to monitor yellow perch reproduction, and were based on locations selected by Ward et al. (2004). A nearshore tow (<100 m from shore) and an offshore tow (>100 m) were collected at each site. Trawl samples were preserved in 70% ethanol and returned to the laboratory for processing and larval fish identification. Larval fishes were identified to species using the Auer (1982) larval fish key. Number of larval yellow perch collected per tow was enumerated, tow volume was determined from flowmeter measurements, and these data were then used to calculate a mean number of larval yellow perch collected per 100 m<sup>3</sup>. The highest average or “peak” mean was used to index annual abundance for subsequent analyses.

Climate data were compiled from the National Oceanic and Atmospheric Administration weather station or municipal airport closest to each lake. Ward et al. (2004) found relationships between larval yellow perch abundance and mean March wind speed, mean May temperature, and total April precipitation in seven eastern South Dakota lakes. Therefore, I used those variables as my *a priori* predictor variables. Monthly means of average daily wind speed and average daily temperature were calculated for March and May from 1995 to 1997 and 2000 to 2008. Total April precipitation was calculated as the sum of all liquid precipitation (e.g., rain, melted snow, etc.) for each day in April from 1995 to 1997 and 2000 to 2008.

Correlation analysis was used to assess the relations between the climatological variables and larval yellow perch abundance. I assessed the relationships between the predictor variables and larval yellow perch abundance by lake and also by combining all lakes. An alpha level of 0.05 was set *a priori* for these analyses. I then used second order

information criterion (AICc, corrected for small sample sizes; Burnham and Anderson 2002) to assess the variability in larval yellow perch abundance. I developed seven models to describe larval yellow perch abundance using the climatological variables and combinations of those variables.

## Results

Larval perch abundance varied widely both within and among study lakes (Table 1-1). Negative correlations were observed between mean March wind speed and larval yellow perch abundance in all lakes except for Lake Pickerel (Figure 3-1). However, the positive relationship found in Lake Pickerel was not statistically significant ( $r = 0.15$ ,  $P = 0.65$ ). Lakes Brant, Madison and Sinai were the only lakes with statistically significant relations (Brant  $r = -0.78$ ,  $P = 0.02$ ; Madison  $r = -0.80$ ,  $P = 0.01$ ; Sinai  $r = -0.77$ ,  $P = 0.009$ ). Additionally, after all lakes were combined, mean March wind speed was significantly and negatively correlated with larval yellow perch abundance ( $r = -0.38$ ,  $P = 0.003$ ; Figure 3-2).

Total April precipitation was positively correlated with larval yellow perch abundance in all lakes except for Lake Pickerel (Figure 3-3). A significant negative correlation was observed for Lake Pickerel ( $r = -0.64$ ,  $P = 0.03$ ). Lakes Brant and Sinai exhibited significant positive correlations (Brant  $r = 0.93$ ,  $P = 0.009$ ; Sinai  $r = 0.87$ ,  $P = 0.001$ ). A significant positive correlation was also observed after all lakes were combined ( $r = 0.35$ ,  $P = 0.006$ ; Figure 3-4).

Positive correlations were observed between mean May temperature and larval yellow perch abundance in the study lakes except for Lake Pickerel (Figure 3-5).

However, none of these relationships were statistically significant including the negative relationship observed for Lake Pickerel. Similar to total April precipitation, a positive correlation was observed after lakes were combined, although not statistically significant ( $r = 0.12$ ,  $P = 0.38$ ; Figure 3-6).

Mean March wind speed was selected as the best candidate model within the AIC analysis explaining variability in larval yellow perch abundance (Table 3-1). However, all other models were competing, indicating limited performance of all models in explaining variation in larval yellow perch abundance.

### **Discussion**

My analysis indicated that larval yellow perch abundance in eastern South Dakota glacial lakes was negatively related to mean March wind speed, and positively related to total April precipitation and mean May temperature. Whether wind, precipitation, or temperature was most influential seemed to vary by lake. These results confirm the relationships between larval yellow perch abundance and the predictor variables reported by Ward et al. (2004). However, these relationships were not strengthened with the additional years of data used in my study. Therefore, my analysis does not improve our understanding of the effects of spring weather patterns on larval yellow perch abundance in eastern South Dakota glacial lakes. My analysis does in fact indicate more variability between the predictor variables and larval yellow perch abundance than previously believed by Ward et al. (2004).

Wind is believed to negatively influence yellow perch by dislodging eggs from the spawning substrate and subsequently cause the eggs to wash ashore (Clady 1976).



The strongest relations between mean March wind speed and larval yellow perch abundance occurred in the three southernmost study lakes (Lakes Brant, Madison, and Sinai). This is surprising because generally yellow perch eggs are not deposited during March. Hanchin et al. (2003) found yellow perch egg masses in Lake Madison in late April and early May of 2000 and 2001. Similarly, Mangan et al. (2005) located yellow perch egg masses in semi-permanent wetlands in east-central South Dakota during mid-April of 2002 and 2003. Therefore, I do not believe that March wind speed caused a direct loss of egg masses in the study lakes. Additionally, I caution that the relationships for Lakes Brant, Sinai, and Waubay are unduly influenced by single data pairs. Further research will be needed to understand why March wind speed is correlated with larval yellow perch abundance.

Lakes Brant and Sinai exhibited significant correlations between larval yellow perch abundance and April precipitation. However, a single data pair had undue influence for the Lake Sinai relationship and thus should be interpreted with caution. April precipitation is believed to be an important predictor variable because increased precipitation translates to an increased amount of flooded vegetation for yellow perch to deposit their eggs. Fisher et al. (1996) noted that yellow perch displayed a preference to spawn eggs onto woody debris in Pickerel Lake, South Dakota. Additionally, Pope et al. (1996) suggested that the positive relationship between precipitation and age-0 yellow perch abundance may be due to the newly inundated woody debris in Lake Brant, South Dakota during spawning. However, there are other potential explanations for my observed correlation between precipitation and larval yellow perch abundance. Perhaps

the decay of newly inundated vegetation results in increased nutrients, thus increasing productivity within the system. The increase in productivity could lead to an increased food supply (e.g., zooplankton) for larval yellow perch. Although April precipitation was correlated with larval yellow perch abundance, the underlying cause of the relationship is still poorly understood.

Mean May temperature was positively correlated with larval yellow perch abundance, although none of the correlations were statistically significant. In addition, undue influence from a single data pair was evident for Lakes Sinai and Waubay. Temperature can both directly and indirectly affect larval fish survival. Newsome and Aalto (1987) suggested that variations in water temperature can cause deformities in yellow perch embryos and could lead to smaller bodied larvae. In addition, cooler water temperatures may hinder zooplankton production (Kalff 2002), which could 1) result in a lower density of available zooplankton for larval yellow perch, or 2) affect the timing between size of available zooplankton and larval perch mouth gape (i.e., match-mismatch hypothesis; Cushing 1990).

My observational analysis of the relationship between the predictor variables and larval yellow perch did not improve our understanding of the role of climatological variables on larval perch in eastern South Dakota waters. Unquestionably, further research is needed to better understand this relationship. Because the most influential predictor variable seemed to vary by lake, I suggest that further analyses should be undertaken on a lake-specific basis. Additionally, monthly metrics of the climatological variables seem to have limited performance in predicting larval yellow perch abundance.

I suggest restricting analyses to smaller time-frame periods. In particular, I suggest that further research is needed on the role of these climatological variables at the time at which larval yellow perch switch to exogenous feeding (see chapter 2). I believe this is a critical period in the early life history of yellow perch in South Dakota and warrants further investigation.

Table 3-1. Akaike's Information Criterion (AIC) values relating larval yellow perch abundance with important predictor variables for Lakes Brant, Enemy Swim, Madison, Pickerel, Sinai, and Waubay in eastern South Dakota. The main effects (in addition to the intercept and error term) are designated as K, n is the number of observations,  $\Delta_i$  is the difference in AICc values. Models were ranked by lowest  $\Delta_i$  values and highest Akaike weight ( $w_i$ ) (i.e. indicates most support). Wind = mean March wind speed (km/h); Precip = total April precipitation (cm); Temp = mean May temperature ( $^{\circ}\text{C}$ ) (see text for complete description of variables).

<i>A priori</i> models	K	n	AICc	$\Delta_i$	$w_i$
Wind	3	58	304.831	0.0000	0.30846
Precip	3	58	305.444	0.6130	0.22703
Precip+Temp	4	58	306.533	1.7028	0.13166
Wind+Precip	4	58	306.537	1.7068	0.13139
Wind+Temp	4	58	307.139	2.3080	0.09728
Wind+Precip+Temp	5	58	308.311	3.4808	0.05412
Temp	3	58	308.467	3.6368	0.05006

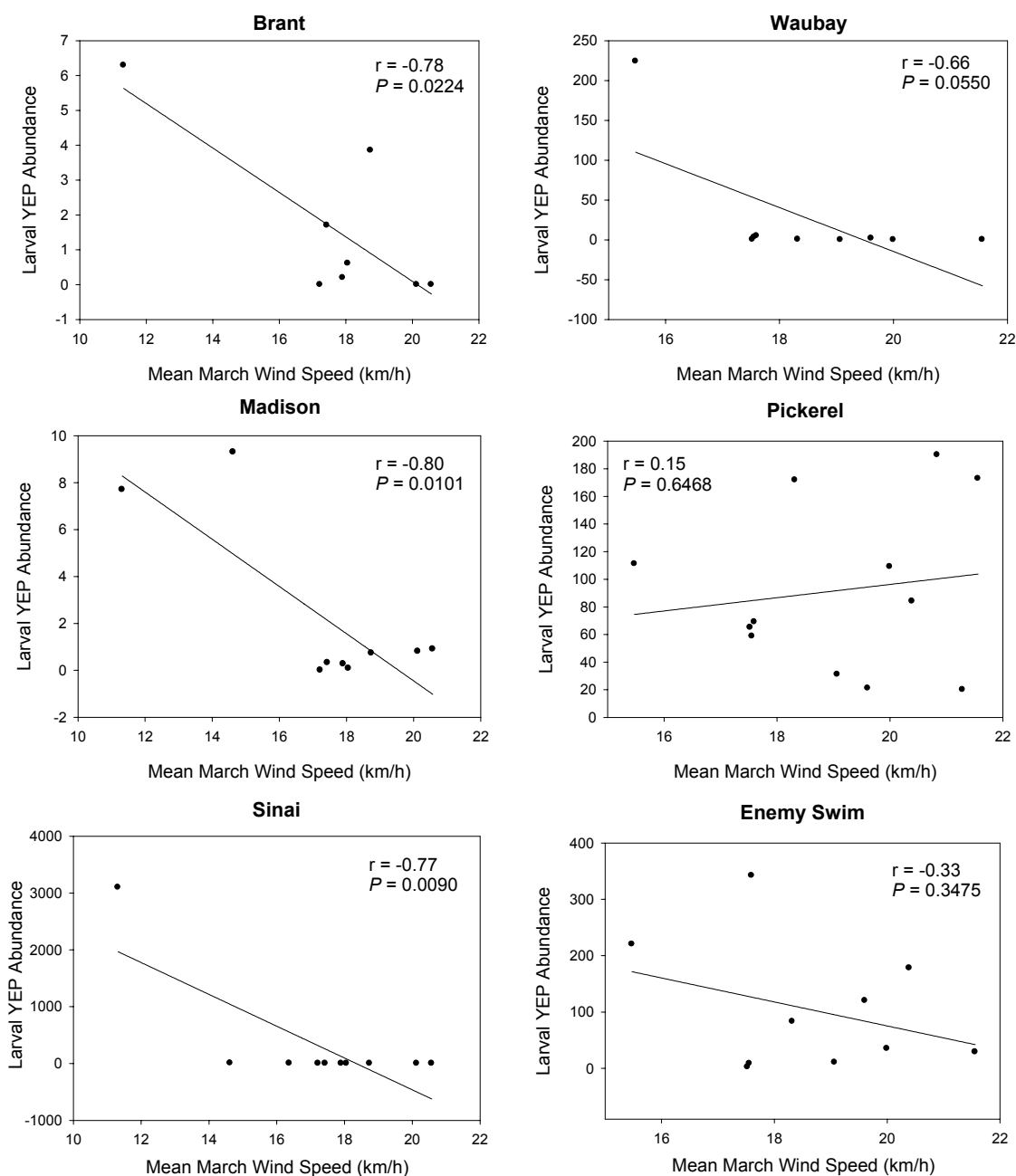


Figure 3-1. Relations between mean March wind speed (km/h) and larval yellow perch (YEP) abundance (number/100 m<sup>3</sup>) determined during larval trawling for six eastern South Dakota glacial lakes sampled from 1995 to 1997 and 2000 to 2008.

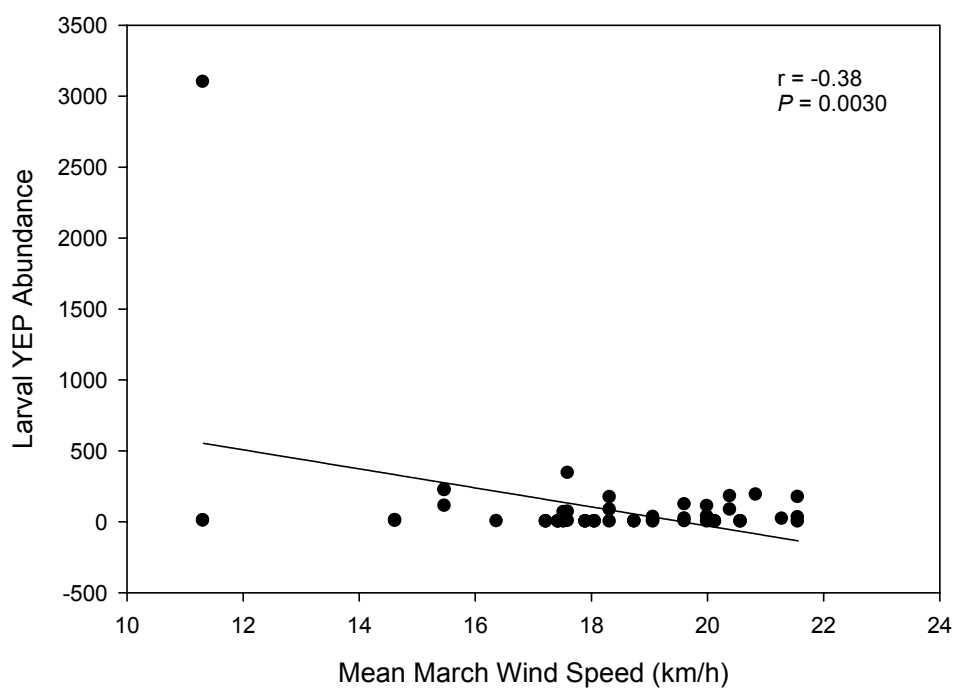


Figure 3-2. Relation between mean March wind speed (km/h) and larval yellow perch (YEP) abundance (number/100 m<sup>3</sup>) determined during larval fish trawling for Lakes Brant, Enemy Swim, Madison, Pickerel, Sinai, and Waubay in eastern South Dakota sampled from 1995 to 1997 and 2000 to 2008.

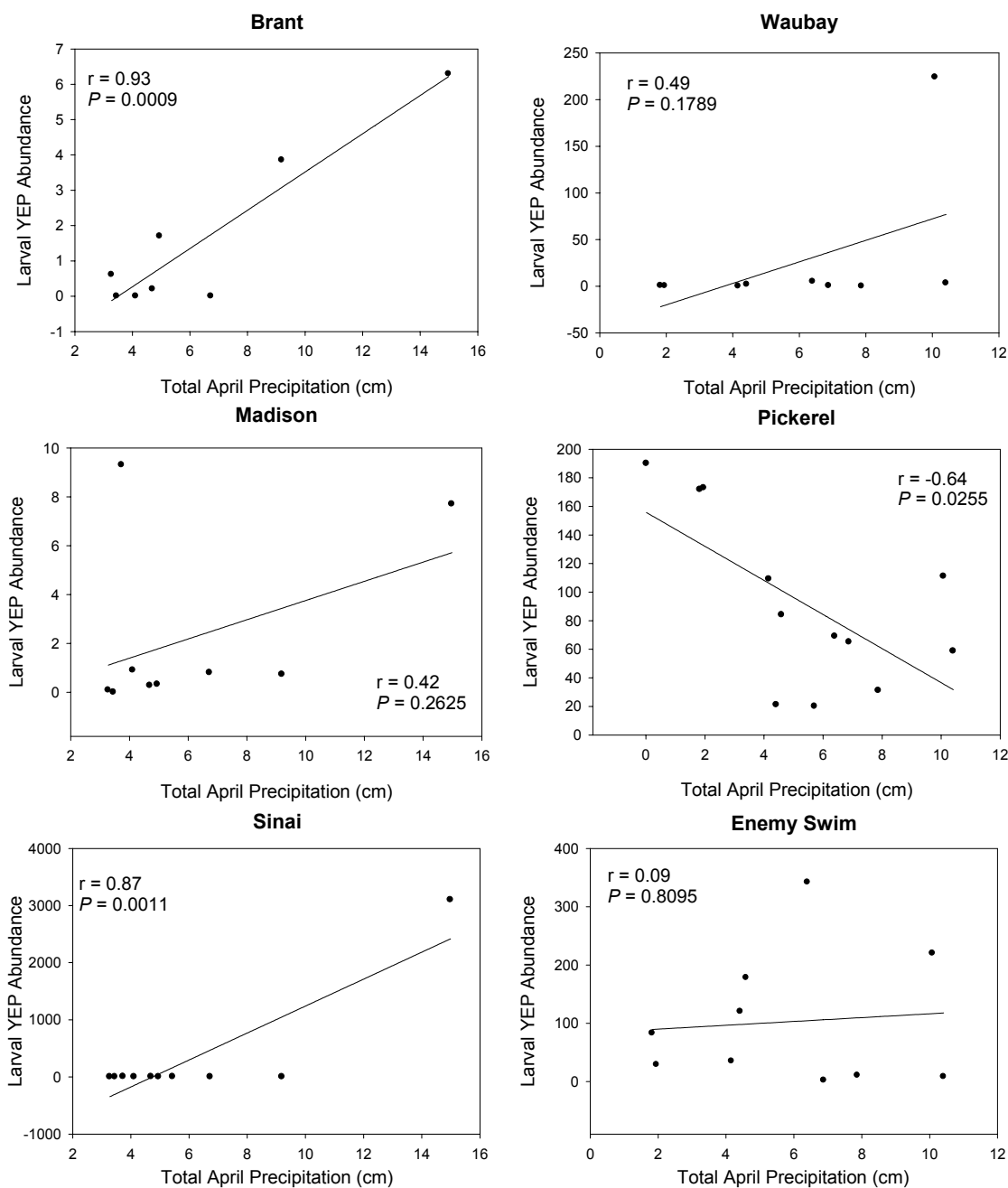


Figure 3-3. Relation between total April precipitation (cm) and larval yellow perch (YEP) abundance (number/100 m<sup>3</sup>) determined during larval fish trawling for six eastern South Dakota glacial lakes sampled from 1995 to 1997 and 2000 to 2008.

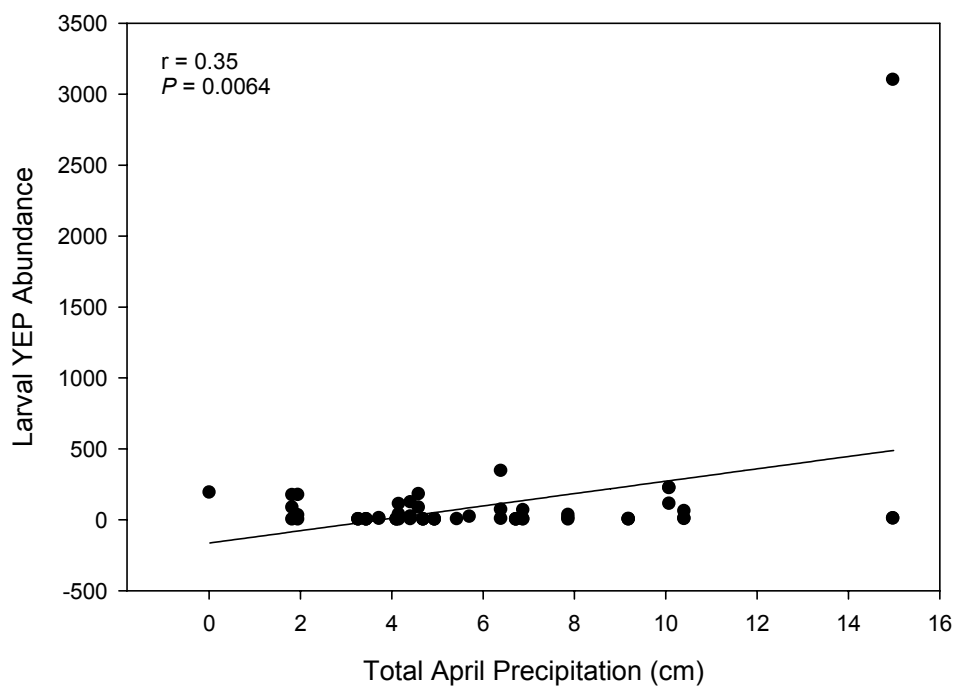


Figure 3-4. Relation between total April precipitation (cm) and larval yellow perch (YEP) abundance (number/100 m<sup>3</sup>) determined during larval fish trawling for Lakes Brant, Enemy Swim, Madison, Pickerel, Sinai, and Waubay in eastern South Dakota sampled from 1995 to 1997 and 2000 to 2008.



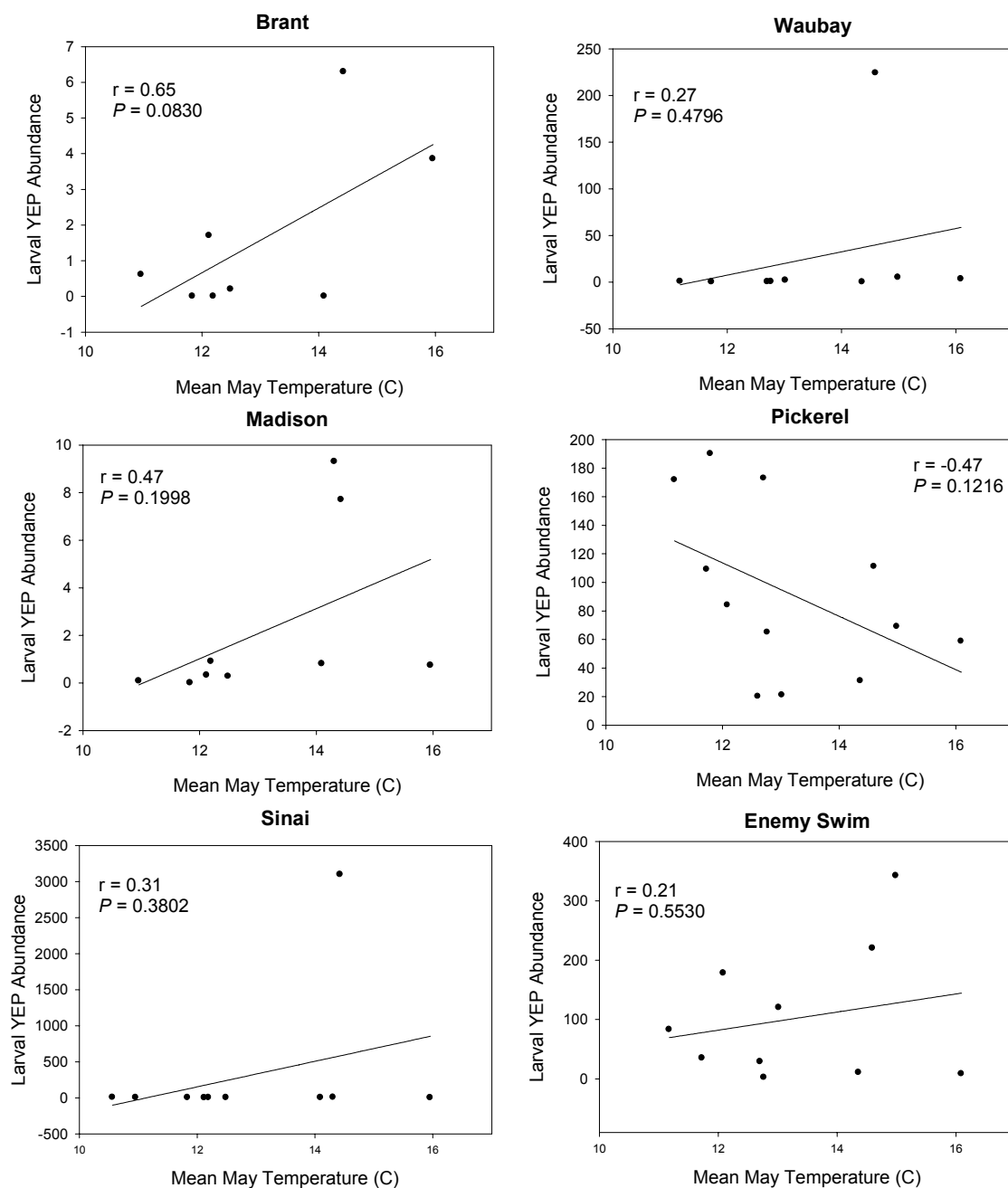


Figure 3-5. Relation between mean May temperature (°C) and larval yellow perch (YEP) abundance (number/100 m<sup>3</sup>) determined during larval fish trawling for six eastern South Dakota glacial lakes sampled from 1995 to 1997 and 2000 to 2008.

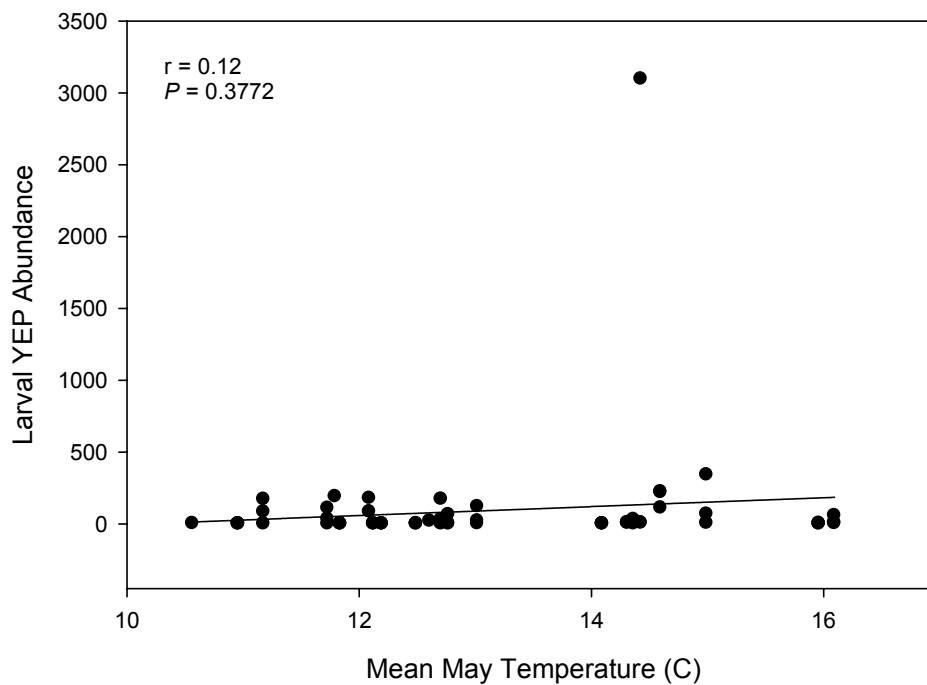


Figure 3-6. Relation between mean May temperature (°C) and larval yellow perch (YEP) abundance (number/100 m<sup>3</sup>) determined during larval fish trawling for Lakes Brant, Enemy Swim, Madison, Pickerel, Sinai, and Waubay in eastern South Dakota sampled from 1995 to 1997 and 2000 to 2008.

## **CHAPTER 4. RELATION BETWEEN AGE-0 YELLOW PERCH ABUNDANCE AND WALLEYE GROWTH AND CONDITION IN EASTERN SOUTH DAKOTA GLACIAL LAKES**

### **Introduction**

Yellow perch are the third most popular sportfish in South Dakota waters (Stone 1996). In addition to their recreational importance, they play a vital role as the primary prey species for many predator species in eastern South Dakota glacial lakes. Walleye are the most popular sportfish in South Dakota waters (Stone 1996) and use yellow perch for prey (Blackwell et al. 1999). Therefore, all aspects of yellow perch population dynamics must be understood to manage percid communities in eastern South Dakota.

Walleye growth and condition have often been related to prey abundance (Forney 1977; Knight et al. 1984; Marwitz and Hubert 1997), but in particular to the abundance of juvenile yellow perch (Forney 1974, 1976; Madenjian 1991; Marwitz and Hubert 1997.) In South Dakota, Meerbeek et al. (2002) reported that walleye growth and condition was positively related to age-0 yellow perch abundance in Lakes Sinai and Waubay. Age-0 walleye growth was significantly faster in 2001 when age-0 yellow perch abundance was higher than in 2000 (Meerbeek et al. 2002). Additionally, walleye condition indices were significantly higher in 2001 than in 2000 for Lakes Sinai and Waubay. However, yellow perch abundances in eastern South Dakota glacial lakes vary widely among years and among lakes (Ward et al. 2004). Many factors have been associated with variable abundance in these systems, but in general, larval yellow perch abundances were higher

during years when spring weather patterns entail more precipitation, warmer air temperature, and less wind (Pope et al. 1996; Ward et al. 2004). If yellow perch are the primary prey of the walleye in these systems and perch abundance varies by year, then walleye population dynamics are also likely to vary by year. Thus, the objective of this study was to assess the extent of the relationship between age-0 yellow perch abundance and walleye growth and condition.

### **Methods**

Larval yellow perch sampling was conducted at Lakes Brant, Enemy Swim, Madison, Pickerel, Sinai, and Waubay in eastern South Dakota (Table 1-1). These lakes range in surface area from 400 to >6,000 ha and are shallow (maximum depth <13 m), meso- to hypereutrophic aquatic systems. Brant Lake was sampled from 2001 to 2008, Lakes Enemy Swim and Sinai were sampled in 1997 and from 2000 to 2008, Lakes Madison and Waubay were sampled from 2000 to 2008, and Pickerel Lake was sampled from 1995 to 1997 and 2000 to 2008.

Larval fish sampling was conducted from early May through mid-June at 7- to 10-d intervals using a 0.75-m, 1,000- $\mu$ m mesh (bar measure) ichthyoplankton surface trawl fitted with a flowmeter (General Oceanics Model #2030R; Miami, Florida) mounted in the mouth of the trawl. The trawl was towed in a circular pattern within the upper 1 m of the water column for 3-5 min at an average speed of 1 m/s. Tow duration was adjusted according to plankton abundance as larval fish capture efficiency decreased as plankton abundance increased. Number of sites sampled per collection trip ranged from three to 10 sites from 1995 to 2003 as study objectives varied across years (Fisher 1996;

Anderson et al. 1997; Isermann 2003; Ward et al. 2004). From 2004 to 2008, three sites were sampled to monitor yellow perch reproduction, and were based on locations selected by Ward et al. (2004). A nearshore tow (<100 m from shore) and an offshore tow (>100 m) were collected at each site. Trawl samples were preserved in 70% ethanol and returned to the laboratory for processing and larval fish identification. Larval fishes were identified to species using the Auer (1982) larval fish key. Number of larval yellow perch collected per tow was enumerated, and tow volume was determined from flowmeter measurements, and these data were then used to calculate a mean number of larval yellow perch collected per 100 m<sup>3</sup>. The highest average or “peak” mean was used to represent annual abundance for subsequent analyses.

Walleye growth, condition, and relative abundance data were compiled from South Dakota Department of Game, Fish and Parks annual lake surveys. These surveys are standardized by location, sampling date, and sampling gear. Walleye growth was indexed as mean total length at time of capture for age-0 walleye during fall, night electrofishing surveys. Walleye condition was indexed as mean relative weight (Wr; fish weight divided by a “standard” weight for a fish of that given length; Anderson and Neumann 1996) of adult walleye by length category (15-25 cm, 25-37 cm, 38-50 cm, 51-62 cm, and 63-76 cm; Gabelhouse 1984). Abundance was indexed as mean number of age-0 walleyes captured per hour of electrofishing (catch per unit effort [CPUE]).

Correlation analysis was used to assess the relationship between biological meaningful predictor variables and age-0 walleye growth. I assessed potential relationships between age-0 walleye growth and age-0 walleye mean CPUE, peak larval

yellow perch abundance (Larv) from surface trawling, and cumulative warming degree days (DegDays). To calculate DegDays, I summed the degree days above 10°C (average daily temperature - 10°C) from April through September of each year of the analysis. Climate data were obtained from the National Oceanic Atmospheric Administration station closest to each lake. I assessed the relationships between the predictor variables and age-0 walleye growth by lake and also by combining all lakes. An alpha level of 0.05 was set *a priori* for these analyses. I then used second order information criterion (AICc, corrected for small sample sizes; Burnham and Anderson 2002) to assess the variability in age-0 walleye growth. Based on the correlation research, I developed seven *a priori* models to describe walleye growth utilizing the predictor variables and combinations of those variables.

## Results

Age-0 walleye growth was weakly correlated with age-0 walleye CPUE (Figure 4-1). Two of the six correlations had a positive slope and only one of the negative correlations was significant (Madison,  $r = -0.73$ ,  $P = 0.04$ ). Similarly, there was little indication of relationships between cumulative warming degree days and walleye growth (Figure 4-2). Weak correlations were observed between larval yellow perch abundance and mean total length of fall age-0 walleye (Figure 4-3). Once again, some correlations were positive and others were negative. Other than perhaps Lake Enemy Swim ( $r = 0.73$ ,  $P = 0.09$ ), there was little evidence of biologically valid relations. Additionally, correlations between the predictor variables and age-0 walleye growth after lakes were combined revealed little support ( $r = 0.05$  to  $0.13$ ; Figures 4-4, 4-5, 4-6). The best

supported AIC analysis model explaining age-0 walleye growth was cumulative warming degree days (lowest  $\Delta_i$  and highest  $w_i$ ) (Table 4-1). The other single variable models (CPUE and Larv) also exhibited substantial support, but combinations of the variables had little support (Table 4-1).

Mean relative weight values for walleyes of various length groups were variable at both high and low larval yellow perch abundances and not consistently related to larval perch abundance (Figures 4-7 to 4-12).

### **Discussion**

Correlations between age-0 walleye growth and my biological predictors were weak or nonexistent both within lakes and among lakes. The most supported AIC model explaining variability in age-0 walleye growth was cumulative warming degree days; however, other single variable models were competing. Thus, walleye growth in my study lakes does not appear to be dependent on age-0 yellow perch abundance, likely due to factors not included in this analysis. One explanation is simply that walleye are utilizing other available prey. Slipke and Duffy (1997) indicated that the most important prey item for sub-stock length walleyes in Shadehill Reservoir was *Daphnia* spp. Larval walleye survival has also been related to daphnid densities (Li and Mathias 1982). Macroinvertebrates can be dominant food items for walleyes in South Dakota glacial lakes, as documented by Isaak et al. (1993) in Lake Thompson. Furthermore, Lott et al. (1996) found that the relative importance of macroinvertebrates in yellow perch diets was positively related to perch growth rates. In years when yellow perch abundance is low, macroinvertebrates could be important as alternative prey for percids such as walleye.

Paradis et al. (2006) contended that invertebrates can provide a large contribution to walleye diet throughout its life cycle as demonstrated in 10 Canadian shield lakes.

Other fishes present in my study lakes, such as spottail shiners, johnny darters, fathead minnows, and black bullheads may contribute to walleye diet and subsequently walleye growth. Isaak et al. (1993) found that fathead minnows and black bullheads were commonly consumed by walleyes in Lake Thompson, South Dakota. Smith and Pycha (1960) indicated that the spottail shiners were a more common food item for walleye than were yellow perch in the Red Lakes, Minnesota; number of spottail shiners in walleye diets exceeded yellow perch in three of six years of study. Moreover, some of my study lakes (Lakes Enemy Swim and Pickerel) also have a centrarchid fish community in addition to the walleye-yellow perch assemblage. The centrarchid species may provide an alternative food source for walleyes. In Spirit Lake, Iowa total consumption of yellow perch by walleye decreased over a 3-year period due to increased consumption of logperch, walleyes (from stocking efforts), largemouth bass, and bluegill (*Lepomis macrochirus*) (Liao et al. 2004).

Another potential explanation for the lack of observed relations between age-0 yellow perch abundance and walleye dynamics in my study lakes could be size-dependent limitations of the available prey. Pelham et al. (2001) found that age-0 yellow perch were consistently too large for age-0 piscivores in Spirit Lake, Iowa from 1997 to 1998. Age-0 piscivores then had to primarily prey on invertebrates and smaller fishes such as johnny darters and bluegills. This size-dependent limitation may vary seasonally. Walleyes consumed small shiners (*Notropis* spp.) in the spring and switched to age-0



clupeids in the summer and autumn in Lake Erie; however, age-0 walleyes were restricted to smaller food items (Knight et al. 1984). In South Dakota, Jackson et al. (1992) found a linear relationship between age-0 walleye length and prey length in Okobojo Bay of Lake Oahe. Walleye food habits changed from zooplankton to piscivory at a mean length of 47 mm (total length) likely due to the suitable size of prey available.

Walleye mean  $W_r$  values were variable among the observed larval yellow perch abundances and among lakes. Again, I believe this is due to the ability of walleye to utilize other available prey items in these systems. Black bullheads were found in stomachs of walleye longer than 38 cm in Lake Thompson, South Dakota along with a variety of invertebrates (Isaak et al. 1993). White bass and aquatic dipteran larvae were dominant prey items for quality- to preferred-length walleye in Shadehill Reservoir, South Dakota (Slipke and Duffy 1997). Johnny darters and emerald shiners were common diet items in July for stock- to quality-length walleye in Lake Poinsett, South Dakota (Starostka 1999). Changes in the prey assemblage due to stocking may alter walleye utilization of food resources. Walleyes utilized gizzard shad (*Dorosoma cepedianum*) after the shad were introduced into Angostura Reservoir, South Dakota. Walleye consumed primarily invertebrates and small fish until age-0 gizzard shad were available from July to early September (Ward et al. 2007). Similarly, walleye diets in Horsetooth Reservoir, Colorado switched from invertebrates and salmonids to rainbow smelt (*Osmerus mordax*) following a smelt introduction (Jones et al. 1994).

The interannual variation in larval yellow perch abundance that I observed seemed to be weakly related to walleye growth and condition in a few study lakes, and

not related in other study waters. In contrast, Meerbeek et al. (2002) found more evidence of age-0 yellow perch abundance leading to increased walleye growth and condition in Lakes Sinai and Waubay (i.e., only two lakes). The Meerbeek et al. (2002) study also assessed differences in walleye growth and condition only during two years. In addition, age-0 yellow perch abundances in 2001 were ten-fold higher than abundances in recent years (Table 1-1). Therefore, although the 2001 walleye year-class utilized the strong 2001 yellow perch year-class, subsequent walleye year classes may have relied on other sources of prey and were thus less affected by yellow perch abundance. My study assessed relations between age-0 yellow perch and walleye growth and condition among lakes up to 11 years. The lack of relationships observed during my study thus provides a more comprehensive understanding of the role of age-0 yellow perch to walleye population dynamics.

Although the systems in my study are relatively simple (basin shape, depth, fish community), complex interactions between walleye and available prey items are likely occurring. I suspect that the diversity of available prey, which varies in abundance and size both seasonally and among years in these systems, provides walleyes with alternative food resources. To better understand walleye growth and condition in eastern South Dakota glacial lakes, I recommend that future research be restricted to lake-specific comparisons. Each of these systems varies in population type (e.g., recruitment, growth, density) and fishery managers would benefit from within lake comparisons. Also in my study, cumulative warming degree days provided the best supported model and thus I

suggest that further investigation into the role of this variable for age-0 walleye growth is warranted.

Table 4-1. Akaike's Information Criterion (AIC) values relating first-year walleye growth with important predictor variables for Lakes Brant, Enemy Swim, Madison, Pickerel, Sinai, and Waubay in eastern South Dakota. The main effects (in addition to the intercept and error term) are designated as K, n is the number of observations,  $\Delta i$  is the difference in AICc values. Models were ranked by lowest  $\Delta i$  values and highest Akaike weight ( $w_i$ ) (i.e. indicates most support). DegDays = cumulative warming degree days (i.e. number of days > 10°C from April-September); CPUE = mean catch per unit effort of age-0 walleyes captured during fall, night electrofishing surveys; Larv = peak larval yellow perch abundance (mean number/100 m<sup>3</sup>) (see text for complete description of variables).

<i>A priori models</i>	K	n	AICc	$\Delta i$	$w_i$
DegDays	3	36	109.374	0.0000	0.27006
CPUE	3	36	109.578	0.2046	0.2438
Larv	3	36	109.589	0.2152	0.24251
Larv+DegDays	4	36	111.875	2.5011	0.07892
DegDays+CPUE	4	36	111.902	2.5278	0.07631
CPUE+Larv	4	36	112.076	2.7026	0.06992
CPUE+Larv+DegDays	5	36	114.573	5.1989	0.02007

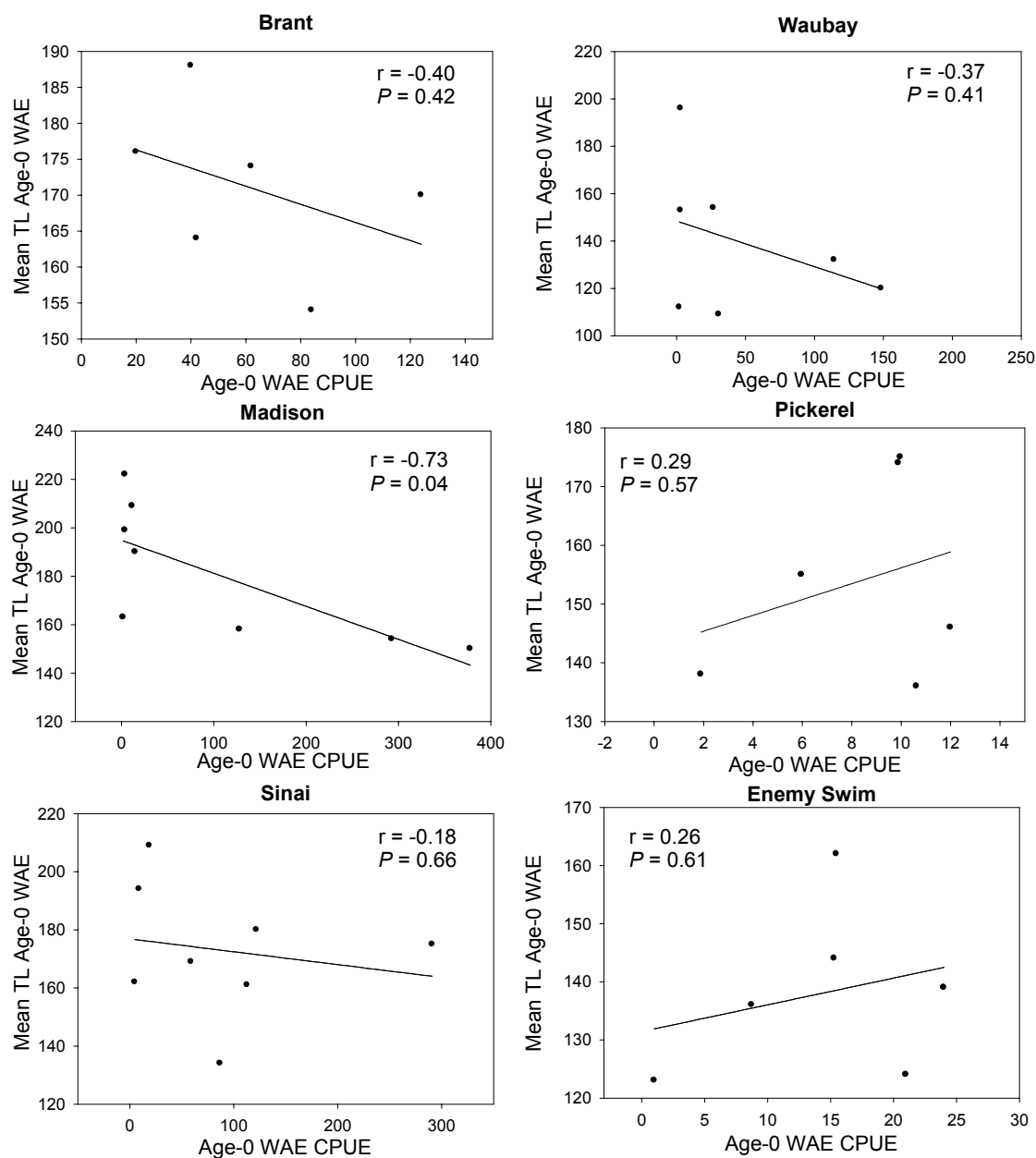


Figure 4-1. Relations between age-0 walleye (WAE) mean catch per unit effort (CPUE) and mean total length (TL) of age-0 walleye captured during fall night electrofishing for six study lakes in eastern South Dakota, 2000-2006.

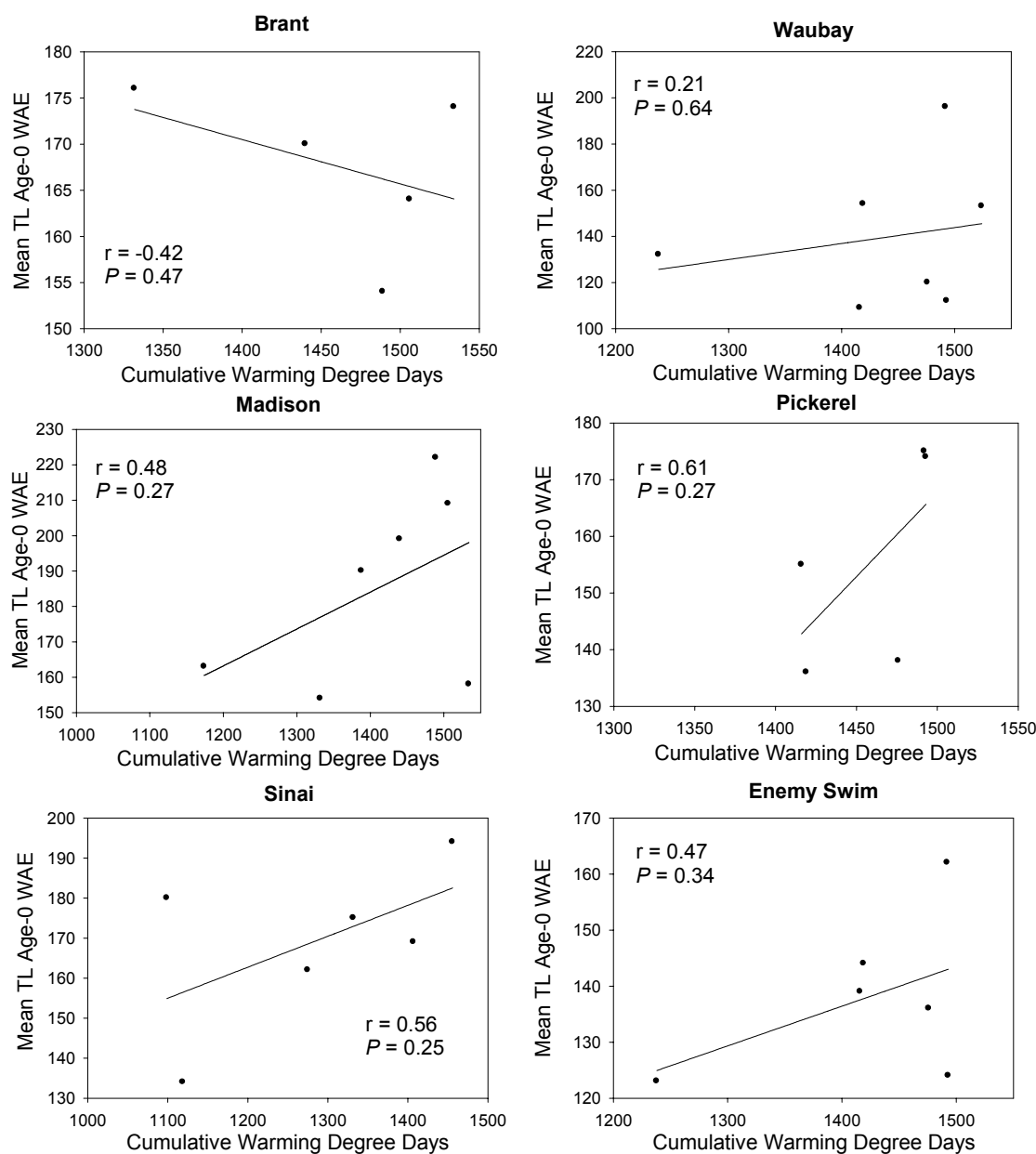


Figure 4-2. Relations between cumulative warming degree days (number of days  $> 10^{\circ}\text{C}$  from April to September) and mean total length (TL) of age-0 walleye (WAE) captured during fall night electrofishing for six study lakes in eastern South Dakota, 2000-2006.

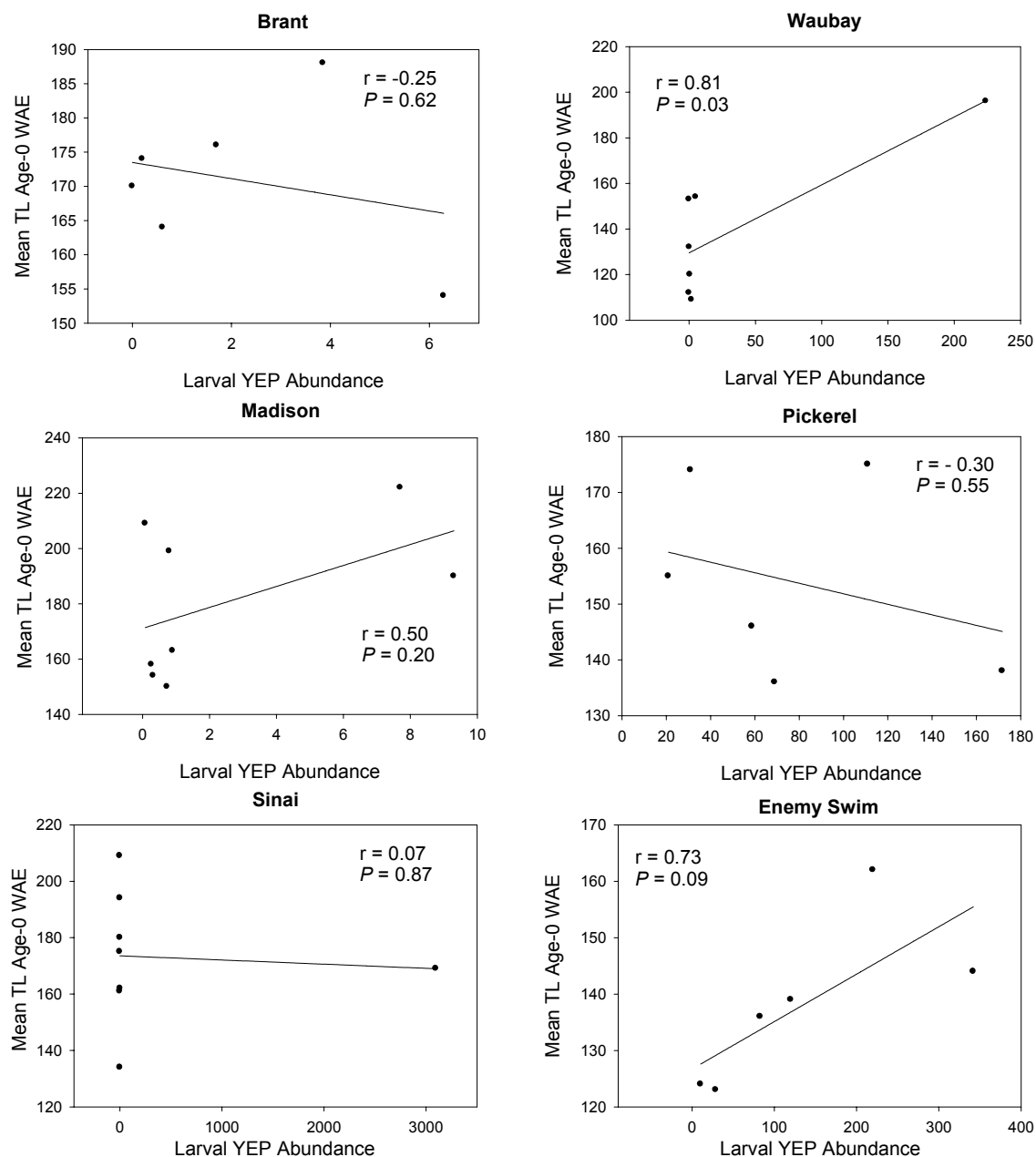
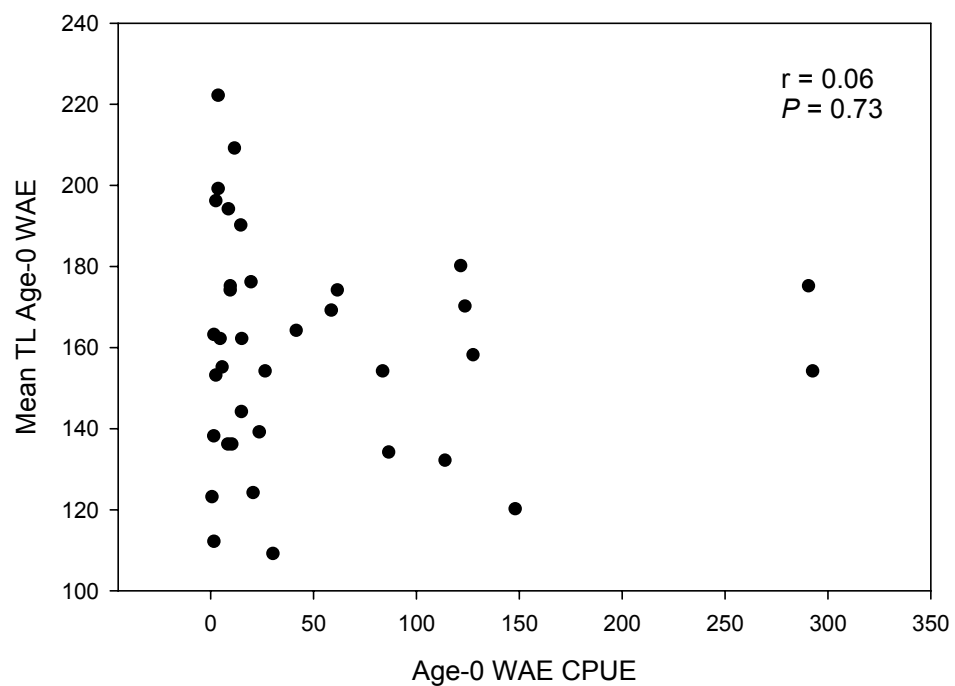


Figure 4-3. Relations between larval yellow perch (YEP) abundance and mean total length (TL) of age-0 walleye (WAE) captured during fall night electrofishing for six study lakes in eastern South Dakota, 2000-2006.





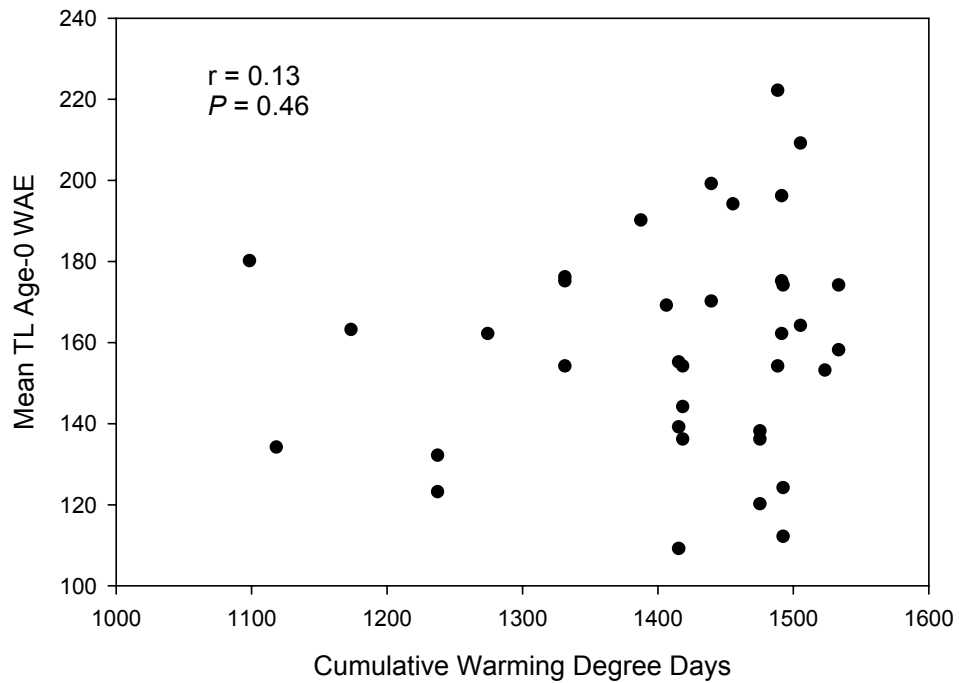


Figure 4-5. Relation between cumulative warming degree days (number of days  $> 10^{\circ}\text{C}$  from April to September) and mean total length (TL) of age-0 walleye (WAE) captured during fall night electrofishing from Lakes Brant, Enemy Swim, Madison, Pickerel, Sinai, and Waubay, 2000-2006.

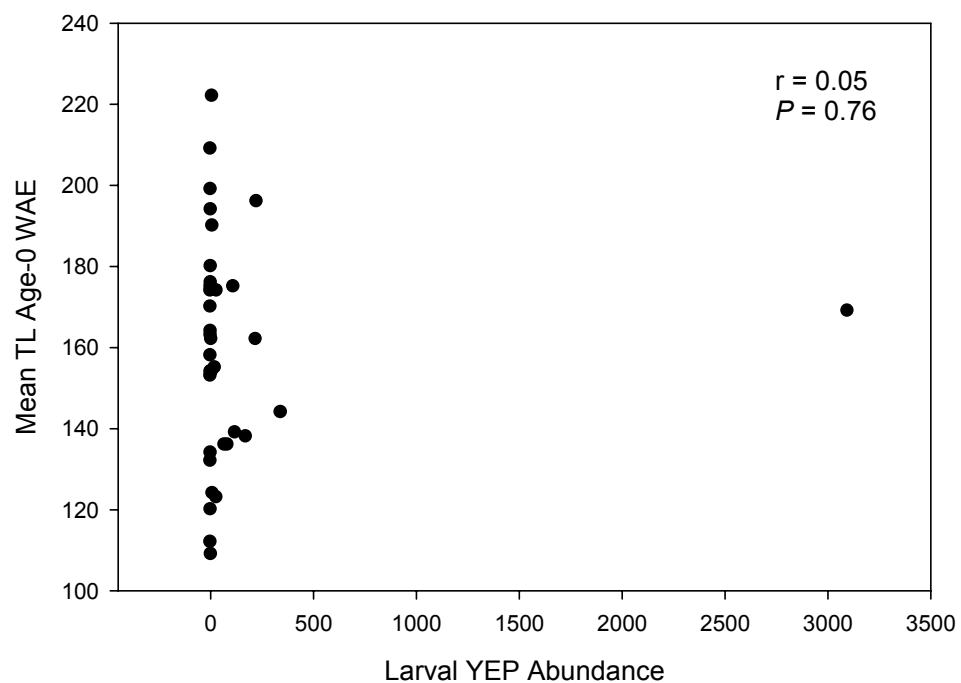


Figure 4-6. Relation between larval yellow perch (YEP) abundance and mean total length (TL) of age-0 walleye (WAE) captured during fall night electrofishing for Lakes Brant, Enemy Swim, Madison, Pickerel, Sinai, and Waubay, 2000-2006.

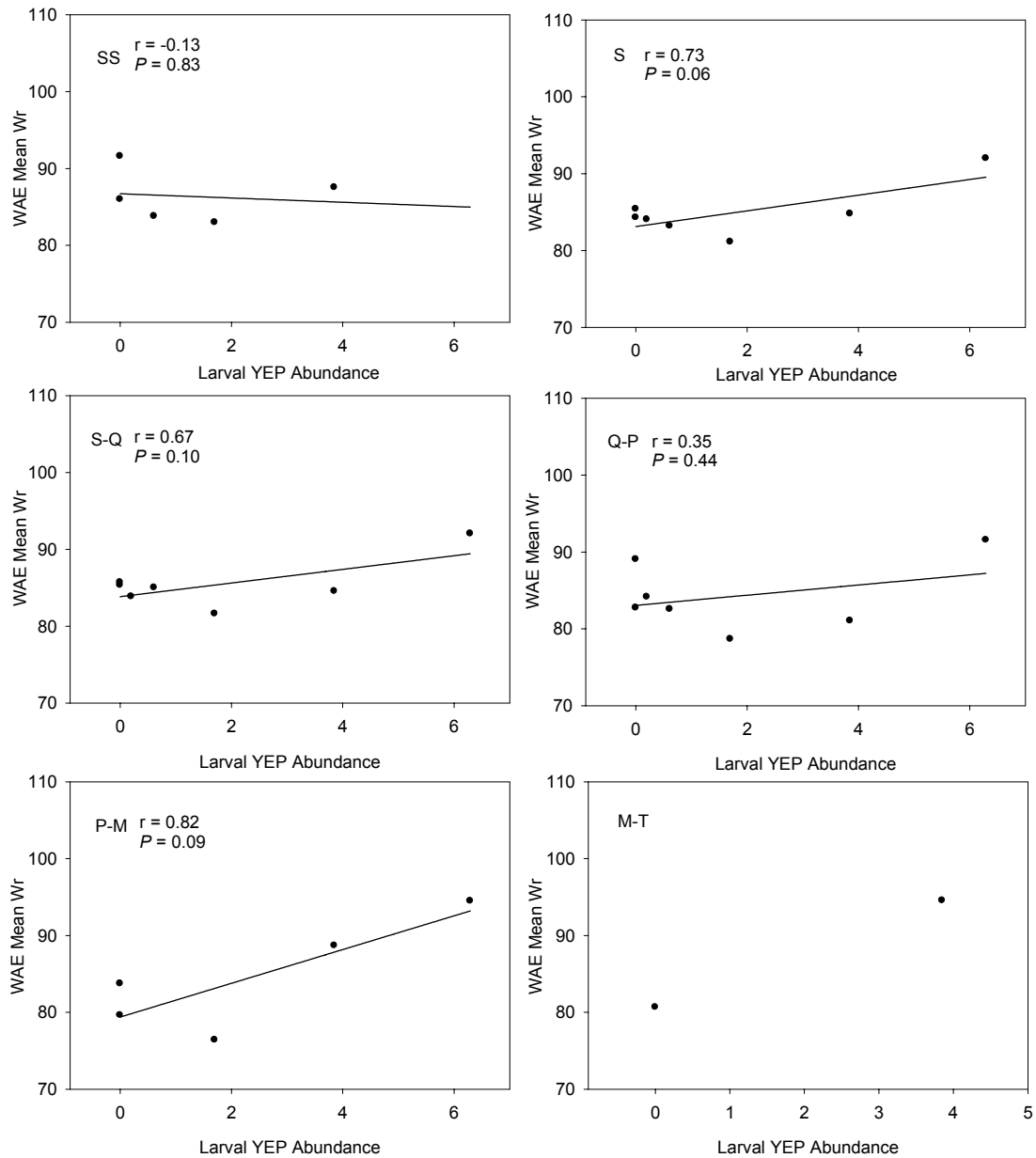


Figure 4-7. Relations between larval yellow perch (YEP) abundance and adult walleye (WAE) mean relative weight (Wr) by length category [Gabelhouse 1984; sub-stock (SS)=15-25 cm; stock (S)=25-76 cm; stock-quality (S-Q)=25-37 cm; quality-preferred (Q-P)=38-50 cm; preferred-memorabile (P-M)=51-62 cm; memorabile-trophy (M-T)=63-76 cm] for Lake Brant in eastern South Dakota, 2001-2007.

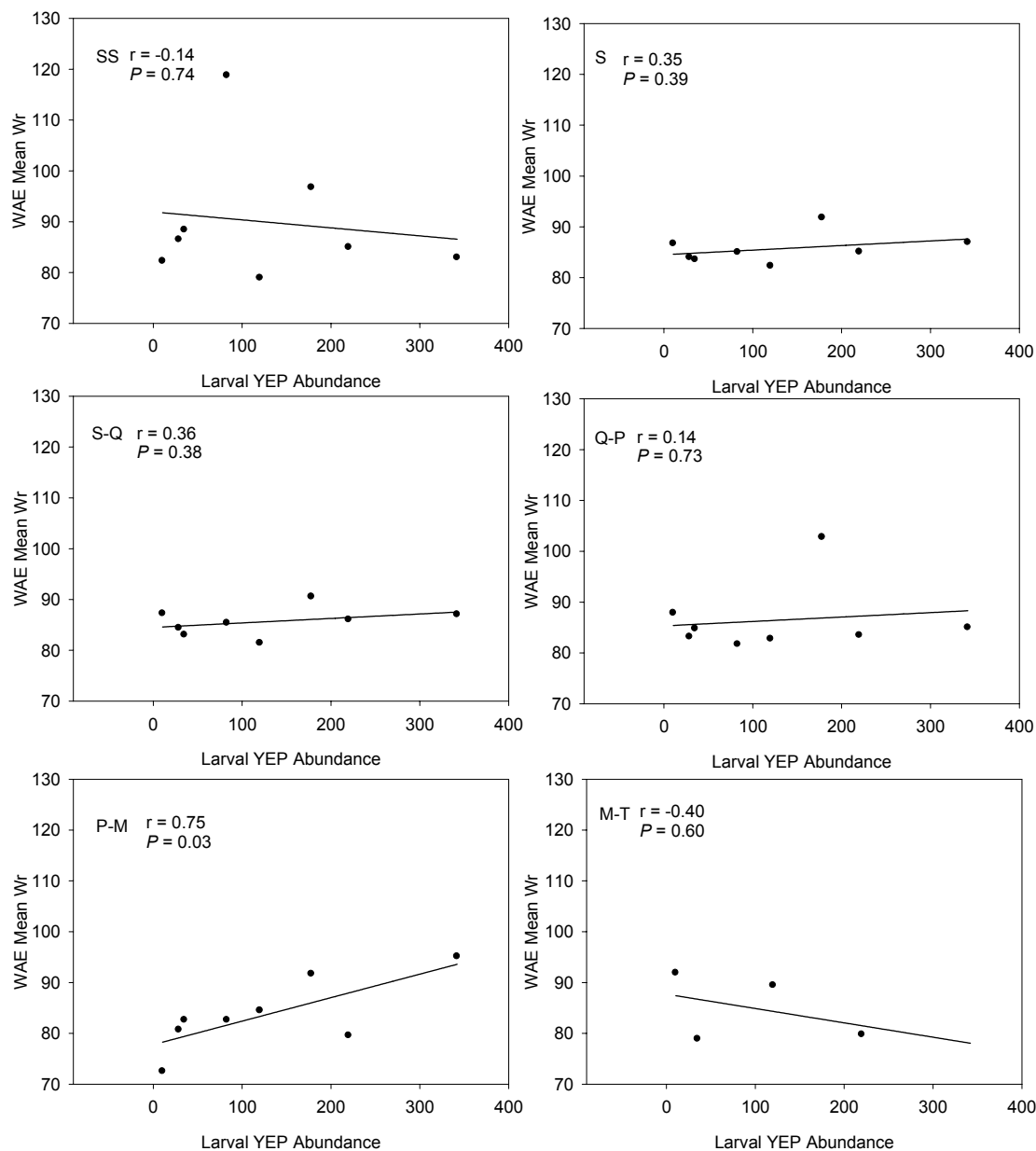


Figure 4-8. Relations between larval yellow perch (YEP) abundance and adult walleye (WAE) mean relative weight (Wr) by length category [Gabelhouse 1984; sub-stock (SS)=15-25 cm; stock (S)=25-76 cm; stock-quality (S-Q)=25-37 cm; quality-preferred (Q-P)=38-50 cm; preferred-memorabile (P-M)=51-62 cm; memorable-trophy (M-T)=63-76 cm] for Lake Enemy Swim in eastern South Dakota sampled in 1997 and from 2000 to 2006.

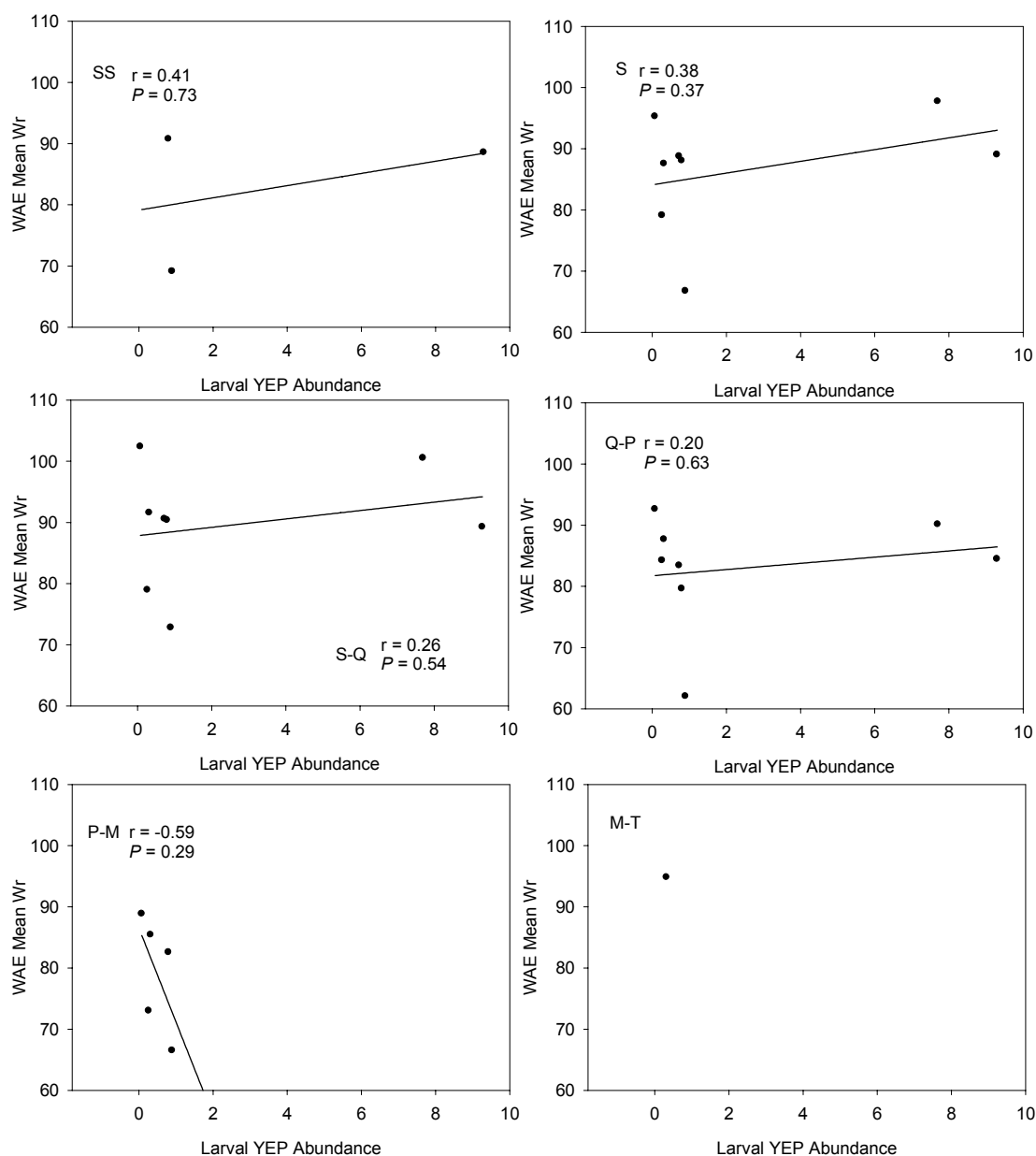


Figure 4-9. Relations between larval yellow perch (YEP) abundance and adult walleye (WAE) mean relative weight (Wr) by length category [Gabelhouse 1984; sub-stock (SS)=15-25 cm; stock (S)=25-76 cm; stock-quality (S-Q)=25-37 cm; quality-preferred (Q-P)=38-50 cm; preferred-memorable (P-M)=51-62 cm; memorable-trophy (M-T)=63-76 cm] for Lake Madison in eastern South Dakota, 2000-2007.

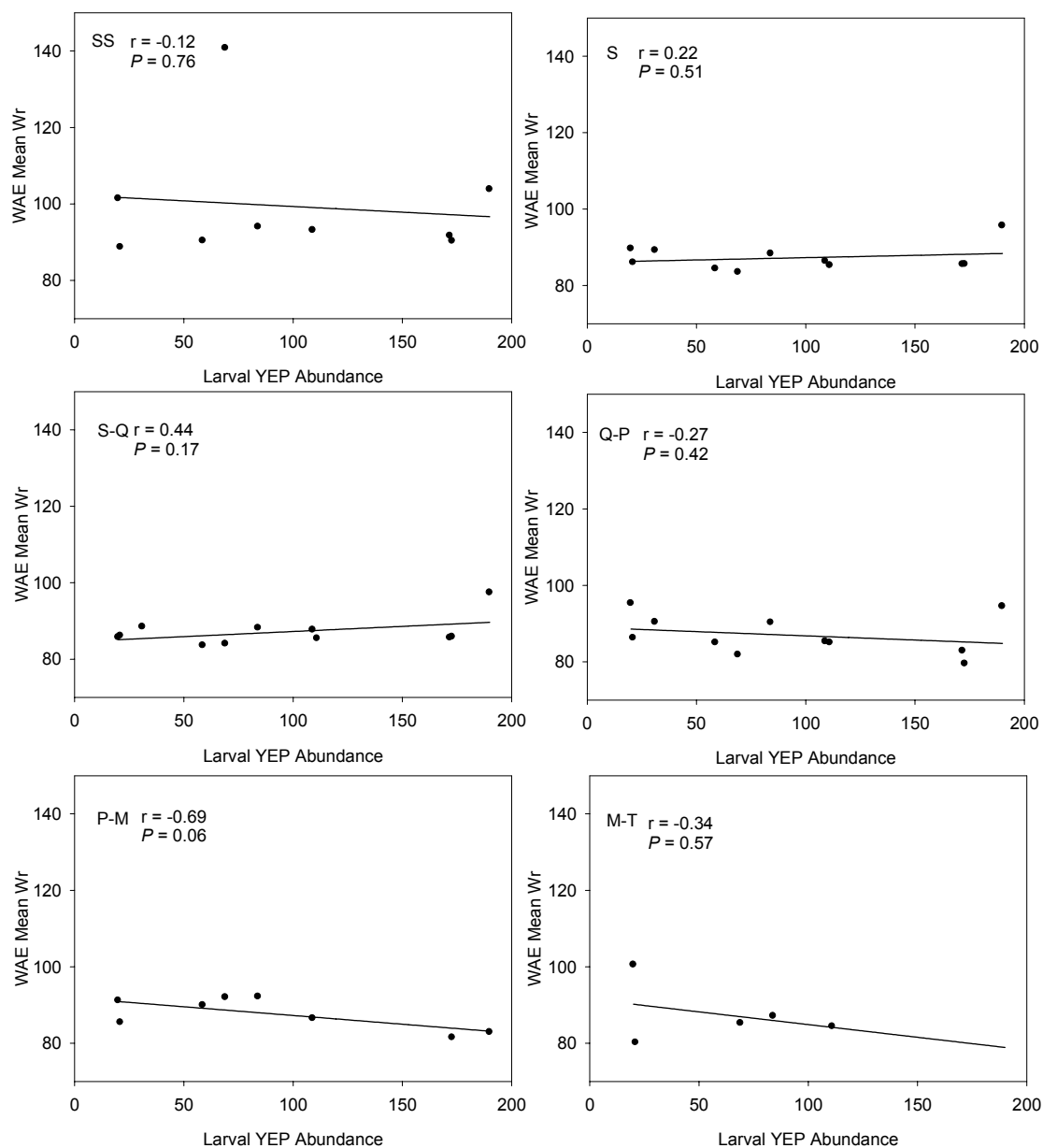


Figure 4-10. Relations between larval yellow perch (YEP) abundance and adult walleye (WAE) mean relative weight (Wr) by length category [Gabelhouse 1984; sub-stock (SS)=15-25 cm; stock (S)=25-76 cm; stock-quality (S-Q)=25-37 cm; quality-preferred (Q-P)=38-50 cm; preferred-memorable (P-M)=51-62 cm; memorable-trophy (M-T)=63-76 cm] for Lake Pickerel in eastern South Dakota sampled from 1995 to 1997 and from 2000 to 2007.

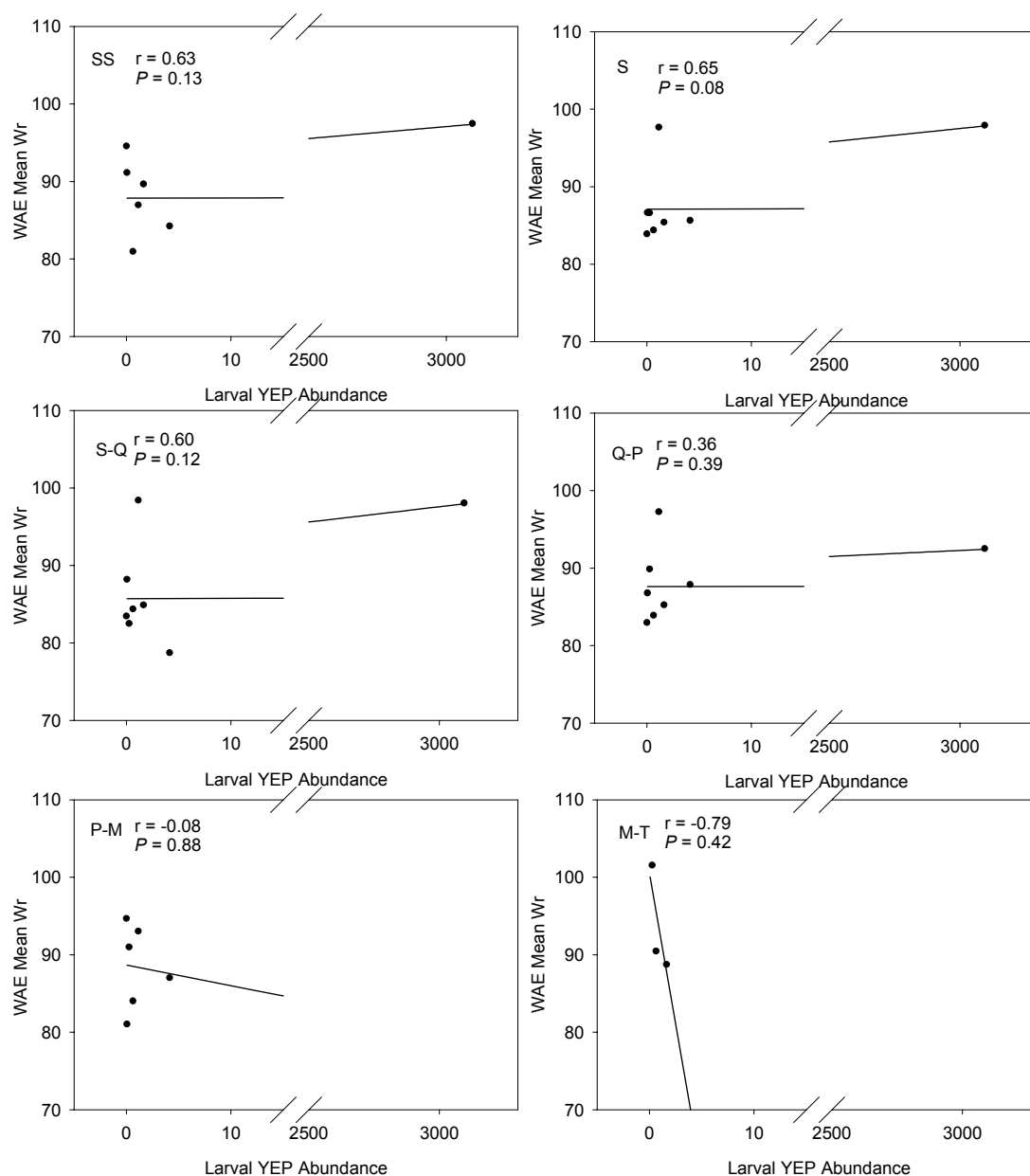


Figure 4-11. Relations between larval yellow perch (YEP) abundance and adult walleye (WAE) mean relative weight (Wr) by length category [Gabelhouse 1984; sub-stock (SS)=15-25 cm; stock (S)=25-76 cm; stock-quality (S-Q)=25-37 cm; quality-preferred (Q-P)=38-50 cm; preferred-memorable (P-M)=51-62 cm; memorable-trophy (M-T)=63-76 cm] for Lake Sinai in eastern South Dakota, 2000-2007.

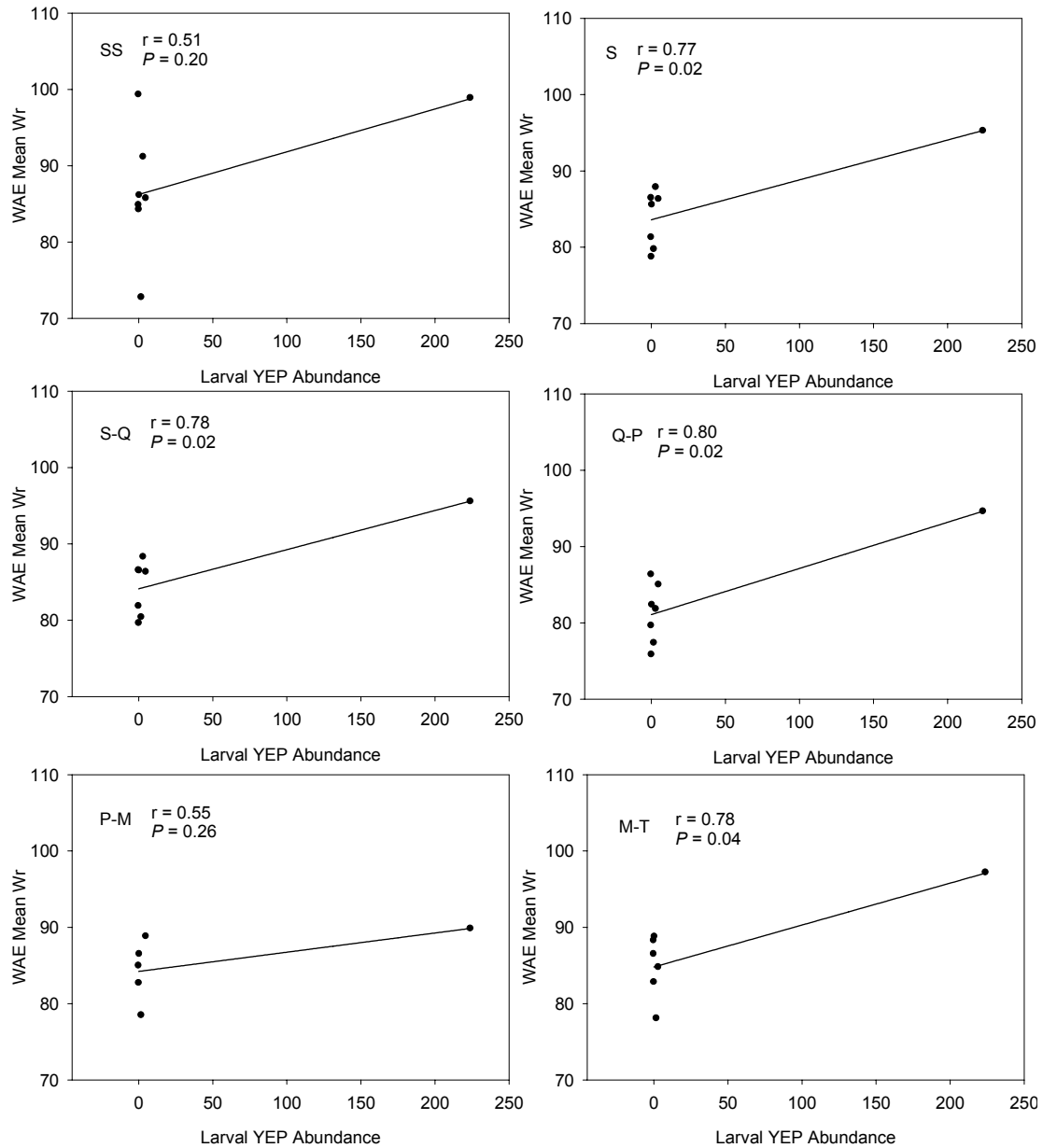


Figure 4-12. Relations between larval yellow perch (YEP) abundance and adult walleye (WAE) mean relative weight (Wr) by length category [Gabelhouse 1984; sub-stock (SS)=15-25 cm; stock (S)=25-76 cm; stock-quality (S-Q)=25-37 cm; quality-preferred (Q-P)=38-50 cm; preferred-memorabile (P-M)=51-62 cm; memorable-trophy length (M-T)=63-76 cm] for Lake Waubay in eastern South Dakota, 2000-2007.



## **CHAPTER 5. SUMMARY AND RESEARCH NEEDS**

Extensive research has been conducted on yellow perch in eastern South Dakota glacial lakes, especially early life history. Yellow perch early life history research has focused on the assessment of introduced spawning habitat, embryo development, life history of larvae and juveniles, and the utility of larvae as a predictor of juvenile abundance and recruitment to the adult population. However, despite research efforts, much is still unknown about yellow perch early life history in eastern South Dakota lakes.

My research on the effect of a rapid decrease in water temperature on mortality of yellow perch eggs indicated that perch eggs are more hardy than previously believed. Even under the “extreme” cold-front conditions, egg survival did not decrease. I believe that this portion of my study provides fishery managers with important information on the effects of spring weather patterns on the egg stage of yellow perch life history. I suggest that further investigation is needed on the effect of rapid decreases in water temperature on the yolk-sac yellow perch larvae as well as at the time when larval perch switch to exogenous feeding. This may be a critical period in yellow perch early life history and further investigation is warranted.

My research on the relation of climatological variables to interannual variation in larval yellow perch abundance did not improve our understanding of these relationships in South Dakota waters. The general correlations that were observed in a previous study were confirmed in my study, but with additional variability. Similar to prior work, the

most influential variable for predicting larval yellow perch abundance seemed to vary by lake, suggesting the need to analyze these natural systems on a lake-specific basis. Additionally, the monthly summaries for climatological data seemed to have limited capability for predicting larval yellow perch abundance. I believe this finding strengthens my suggestion to further investigate the timing of the yellow perch change from endogenous to exogenous feeding. Perhaps variation in spring weather patterns at a smaller scale (e.g., weeks at which larval yellow perch begin feeding) may play a critical role in determining larval perch abundance.

Weak relationships were observed between larval yellow perch abundance and walleye growth and condition. This suggests that walleyes consume alternative prey items in the absence of yellow perch. Complex interactions between the fish community and alternative food sources make predator-prey relationship comparisons between walleye and yellow perch difficult in these systems. The most influential variable in predicting walleye growth varied by lake. Therefore, I suggest that further analyses should be undertaken on a lake-specific basis. Cumulative warming degree days seemed to indicate some support for explanation of walleye growth in a few of the study lakes and thus should be further evaluated in future analyses.

Another research avenue that I believe warrants further investigation is first-year, over-winter mortality of yellow perch. Initial research indicated that larval yellow perch abundance was correlated with fall juvenile catches (Anderson et al. 1998). Additional research found that larval yellow perch abundance had limited utility in predicting subsequent recruitment (Isermann 2003). Therefore, I suggest that a study is needed to

determine if first-year, over-winter mortality is significant in determining subsequent recruitment. I believe these research avenues will provide a better understanding of the factors that affect yellow perch recruitment in eastern South Dakota waters.

## REFERENCES

- Aalto, S.K., and G.E. Newsome. 1993. Winds and the demic structure of a population of yellow perch (*Perca flavescens*). Canadian Journal of Fisheries and Aquatic Sciences 50:496-501.
- Anderson, M.R., S.J. Fisher, and D.W. Willis. 1997. Assessment of an early index to yellow perch recruitment in eastern South Dakota glacial lakes. South Dakota Department of Game, Fish and Parks, Fisheries Division Report 97-17, Pierre.
- Anderson, M.R., S.J. Fisher, and D.W. Willis. 1998. Relationship between larval and juvenile yellow perch abundance in eastern South Dakota glacial lakes. North American Journal of Fisheries Management 18:989-991.
- Anderson, R.O., and R.M. Neumann. 1996. Length, weight, and associated structural indices. Pages 447-482 in B.R. Murphy and D.W. Willis, editors. Fisheries techniques, 2<sup>nd</sup> edition. American Fisheries Society, Bethesda, Maryland.
- Auer, N.A. 1982. Identification of larval fishes in the Great Lakes basin with emphasis on the Lake Michigan drainage. Great Lakes Fishery Commission, Special Publication 82-3, Ann Arbor, Michigan.
- Blackwell, B.G., C.A., Soupir, and M.L. Brown. 1999. Seasonal diets of walleye and diet overlap with other top-level predators in two South Dakota lakes. South Dakota Department of Game, Fish and Parks, Fisheries Division Report 99-23, Pierre.

- Burnham, K.P., and D.R. Anderson. 2002. Model selection and multi-model inference: a practical information-theoretic approach, 2<sup>nd</sup> edition. Springer-Verlag, New York.
- Carlson, R.E. 1977. A trophic state index for lakes. *Limnology and Oceanography* 22:361-369.
- Clady, M.D. 1976. Influence of temperature and wind on the survival of early stages of yellow perch, *Perca flavescens*. *Journal of the Fisheries Research Board of Canada* 33:1887-1893.
- Clady, M., and B. Hutchinson. 1975. Effect of high winds on eggs of yellow perch, *Perca flavescens*, in Oneida Lake, New York. *Transactions of the American Fisheries Society* 104:524-525.
- Cushing, D.H. 1990. Plankton production and year-class strength in fish populations: an update of the match/mismatch hypothesis. *Advances in Marine Biology* 26:249-293.
- Diamond, M., and P.M. Wakefield. 1986. The consumption of eggs of the perch, *Perca fluviatilis* L., by macroinvertebrates in the field. *Freshwater Biology* 16:373-376.
- Eshenroder, R.L. 1977. Effects of intensified fishing, species change, and spring water temperatures on yellow perch, *Perca flavescens*, in Saginaw Bay. *Journal of the Fisheries Research Board of Canada* 34:1830-1838.
- Fisher, S.J. 1996. Early life history of yellow perch in eastern South Dakota lakes. Master's thesis. South Dakota State University, Brookings.

- Fisher, S.J., K.L. Pope, L.J. Templeton, and D.W. Willis. 1996. Yellow perch spawning habitats in Pickerel Lake, South Dakota. *The Prairie Naturalist* 28:65-75.
- Forney, J.L. 1974. Interactions of yellow perch abundance and walleye predation, and survival of alternate prey from Oneida Lake, New York. *Transactions of the American Fisheries Society* 103:15-24.
- Forney, J.L. 1976. Year-class formation in the walleye (*Stizostedion vitreum vitreum*) population of Oneida Lake, New York, 1963-1973. *Journal of the Fisheries Research Board of Canada* 33:783-792.
- Forney, J.L. 1977. Reconstruction of yellow perch (*Perca flavescens*) cohorts from examination of walleye (*Stizostedion vitreum vitreum*) stomachs. *Journal of the Fisheries Research Board of Canada* 34:925-932.
- Gabelhouse, D.W., Jr. 1984. A length-categorization system to assess fish stocks. *North American Journal of Fisheries Management* 4:273-285.
- Geist, D.R., C. Scott Abernathy, K.D. Hand, V.I. Cullinan, J.A. Chandler, and P.A. Groves. 2006. Survival, development, and growth of fall Chinook salmon embryos, alevins, and fry exposed to variable thermal and dissolved oxygen regimes. *Transactions of the American Fisheries Society* 135:1462-1477.
- Graeb, B.D.S., J.M. Dettmers, D.H. Wahl, and C.E. Caceres. Fish size and prey availability affect growth, survival, prey selection, and foraging behavior of larval yellow perch. *Transactions of the American Fisheries Society* 133:504-514.

- Guma'a, S.A. 1978. The effects of temperature on the development and mortality of eggs of perch, *Perca fluviatilis*. *Freshwater Biology* 8:221-227.
- Hanchin, P.A., D.W. Willis, and T.R. St. Sauver. 2003. Influence of introduced spawning habitat on yellow perch reproduction in Lake Madison, South Dakota. *Journal of Freshwater Ecology* 18:291-298.
- Henderson, B.A. 1985. Factors affecting growth and recruitment of yellow perch, *Perca flavescens* Mitchell, in South Bay, Lake Huron. *Journal of Fish Biology* 26:449-458.
- Heyer, C.J., T.J. Miller, F.P. Binkowski, E.M. Caldarone, and J.A. Rice. 2001. Maternal effects as a recruitment mechanism in Lake Michigan yellow perch (*Perca flavescens*). *Canadian Journal of Fisheries and Aquatic Sciences* 58:1477-1487.
- Hokanson, K.E.F., and C.F. Kleiner. 1974. Effects of constant and rising temperatures on survival and developmental rates of embryonic and larval yellow perch, *Perca flavescens* (Mitchell). Pages 437-448 in J.H.S. Blaxter, editor. *The early life history of fishes*. Springer-Verlag, New York.
- Huff, D.D., G. Grad, and C.E. Williamson. 2004. Environmental constraints on spawning depth of yellow perch: the roles of low temperature and high solar ultraviolet radiation. *Transactions of the American Fisheries Society* 133:718-726.
- Isaak, L.C., R.M. Neumann, and D.W. Willis. 1993. Food habits of walleyes in Lake Thompson, South Dakota. *Prairie Naturalist* 25:325-330.

- Isermann, D.A. 2003. Population dynamics and management of yellow perch populations in South Dakota glacial lakes. Doctoral dissertation. South Dakota State University, Brookings.
- Isermann, D.A., P.A. Hanchin, and D.W. Willis. 2002. Comparison of two mesh sizes for collecting larval yellow perch in surface trawls. *North American Journal of Fisheries Management* 22:585-589.
- Isermann, D.A., and D.W. Willis. 2008. Emergence of larval yellow perch, *Perca flavescens*, in South Dakota lakes: potential implications for recruitment. *Fisheries Management and Ecology* 15:259-271.
- Jackson, J.J., D.W. Willis, and D.G. Fielder. 1992. Food habits of young-of-the-year walleyes in Okobojo Bay of Lake Oahe, South Dakota. *Journal of Freshwater Ecology* 7:329-341.
- Johnston, T.A., M.D. Wiegand, W.C. Leggett, R.J. Pronyk, S.D. Dyal, K.E. Watchcorn, S. Kollar, and J.M. Casselman. 2007. Hatching success of walleye embryos in relation to maternal and ova characteristics. *Ecology of Freshwater Fish* 16:295-306.
- Jones, M.S., J.P. Goettl Jr., and S.A. Flickinger. 1994. Changes in walleye food habits and growth following a rainbow smelt introduction. *North American Journal of Fisheries Management* 14:409-414.
- Kalff, J. 2002. *Limnology*. Prentice-Hall, Upper Saddle River, New Jersey.



- Kallemeyn, L.W. 1987. Correlations of regulated lake levels and climatic factors with abundance of young-of-the-year walleye and yellow perch in four lakes in Voyageurs National Park. *North American Journal of Fisheries Management* 7:513-521.
- Knight, R.L., F.J. Margraf, and R.F. Carline. 1984. Piscivory by walleyes and yellow perch in western Lake Erie. *Transactions of the American Fisheries Society* 113:677-693.
- Lapointe M.F., N.E. Bergeron., F. Berube, M.-A. Pouliot, and P. Johnston. 2004. Interactive effects of substrate sand and silt contents, redd-scale hydraulic gradients, and interstitial velocities on egg-to-emergence survival of Atlantic salmon (*Salmo salar*). *Canadian Journal of Fisheries and Aquatic Sciences* 61:2271-2277.
- Levasseur, M., N.E. Bergeron, M.F. Lapointe, and F. Berube. 2006. Effects of silt and very fine sand dynamics in Atlantic salmon (*Salmo salar*) redds on embryo hatching success. *Canadian Journal of Fisheries and Aquatic Sciences* 63:1450-1459.
- Li, S., and J.A. Mathias. 1982. Causes of high mortality among cultured larval walleyes. *Transactions of the American Fisheries Society* 111:710-721.
- Liao, H., C.L. Pierce, and J.G. Larscheid. 2004. Consumption dynamics of the adult piscivorous fish community in Spirit Lake, Iowa. *North American Journal of Fisheries Management* 24:890-902.

- Longhenry, C.M., 2006. Yellow perch production in semi-permanent wetlands in eastern South Dakota and evaluation of a new chemical marking tool for juvenile yellow perch. Master's thesis, South Dakota State University, Brookings.
- Lott, J.P., D.W. Willis, and D.O. Lucchesi. 1996. Relationship of food habits to yellow perch growth and population structure in South Dakota lakes. *Journal of Freshwater Ecology* 11:27-37.
- Madenjian, C.P. 1991. Limits to growth of young-of-the-year walleye (*Stizostedion vitreum vitreum*): an individual-based model perspective. *Canadian Journal of Fisheries and Aquatic Sciences* 48:1492-1499.
- Mangan, M.T., M.L. Brown, and T.R. St. Sauver. 2005. Yellow perch use of introduced spawning habitat. *Journal of Freshwater Ecology* 20:381-388.
- Marwitz, T.D., and W.A. Hubert. 1997. Trends in relative weight of walleye stocks in Wyoming reservoirs. *North American Journal of Fisheries Management* 17:44-53.
- Meerbeek, J.R., D.A. Isermann, and D.W. Willis. 2002. Influence of age-0 yellow perch abundance on walleye populations in two eastern South Dakota lakes. *Proceedings of the South Dakota Academy of Science* 81:93-99.
- Newsome, G.E., and J. Tompkins. 1985. Yellow perch egg masses deter predators. *Canadian Journal of Zoology* 63:2882-2884.
- Newsome, G.E., and S.K. Aalto. 1987. An egg-mass census method for tracking fluctuations in yellow perch (*Perca flavescens*) populations. *Canadian Journal of Fisheries and Aquatic Sciences* 44:1221-1231.

- Paradis, Y., A. Bertolo, A. Perot, S. Debas, and P. Magnan. 2006. Do benthivory and piscivory result in similar growth in walleye? *Journal of Fish Biology* 69:1317-1329.
- Pelham, M.E., C.L. Pierce, and J.G. Larscheid. 2001. Diet dynamics of the juvenile piscivorous fish community in Spirit Lake, Iowa, USA, 1997-1998. *Ecology of Freshwater Fish* 10:198-211.
- Pope, K.L., D.W. Willis, and D.O. Lucchesi. 1996. Differential relations of age-0 black crappie and yellow perch to climatological variables in a natural lake. *Journal of Freshwater Ecology* 11:345-350.
- Post, J.R., and D.J. McQueen. 1988. Ontogenetic changes in the distribution of larval and juvenile yellow perch (*Perca flavescens*): a response to prey or predators? *Canadian Journal of Fisheries and Aquatic Sciences* 45:1820-1826.
- Reiser, D.W., and R.G. White. 1988. Effects of two sediment size-classes on survival of steelhead and Chinook salmon eggs. *North American Journal of Fisheries Management* 8:432-437.
- SAS Institute. 2004. Base SAS<sup>®</sup> 9.1 Procedures Guide. SAS Institute, Cary, North Carolina.
- Sifa, L., and J.A. Mathias. 1987. The critical period of high mortality of larvae fish—a discussion based on current research. *Chinese Journal of Oceanology and Limnology* 5:79-98.
- Slipke, J.W., and W.G. Duffy. 1997. Food habits of walleye in Shadehill Reservoir, South Dakota. *Journal of Freshwater Ecology* 12:11-17.

- Smith, L.L., J.r., and R.L. Pycha. 1960. First-year growth of the walleye, *Stizostedion vitreum vitreum* (Mitchell), and associated factors in the Red Lakes, Minnesota. *Limnology and Oceanography* 5:281-290.
- Starostka, A.B. 1999. Food habits and diet overlap of age-1 and older walleye and white bass in Lake Poinsett, South Dakota. Master's thesis. South Dakota State University, Brookings.
- Stone, C. 1996. South Dakota angler use and preference survey: supplement 2 data break-down by management region and fisheries program areas. South Dakota Department of Game, Fish and Parks, Fisheries Division Supplemental Report 96-2, Pierre.
- Stueven, E., and W.C. Stewart. 1996. 1995 South Dakota lakes assessment final report. South Dakota Department of Environment and Natural Resources, Pierre.
- Stukel, S.M. 2003. Assessing the sustainability of fish communities in glacial lakes: habitat inventories and relationships between lake attributes and fish communities. Master's thesis. South Dakota State University, Brookings.
- Ward, M.J., M.R. Anderson, S.J. Fisher, D.A Isermann, Q.E. Phelps, and D.W. Willis. 2004. Relations between climatological variables and larval yellow perch abundance in eastern South Dakota glacial lakes. *Journal of Freshwater Ecology* 19:213-218.
- Ward, M.J., D.W. Willis, B.H. Miller, and S.R. Chipps. 2007. Walleye consumption and long-term population trends following gizzard shad introduction into a western South Dakota reservoir. *Journal of Freshwater Ecology* 22:339-345.

Wells, L. 1977. Changes in yellow perch (*Perca flavescens*) populations of Lake Michigan, 1954-75. Journal of the Fisheries Research Board of Canada 34:1821-1829.